



ASIAN HONEYBEE

POSSIBLE ENVIRONMENTAL IMPACTS

Prepared for the Department of Sustainability, Environment,
Water, Population and Communities

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June 2011

June 2011

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Cover image by A. Carr (landscape) and D. Anderson (bees).

Citation: Carr, A. 2011. Asian Honeybee: Potential Environmental Impacts. Report for the Department of Sustainability, Environment, Water, Population and Communities. Sustineo Pty Ltd. Canberra.

Acknowledgements

I would like to acknowledge Denis Anderson and Dean Paini from CSIRO who reviewed the document and provided excellent leads on reference sources. I would also like to thank Paul de Barro, Mark Leech, Sarah Goswami, Corey Bell, David Paton, Bill Doherty, Dave Alden, Andrew Rowe and Trudi Prideaux for their various contributions of references, maps, photographs technical assistance and/or advice in the preparation of this review.

Abbreviations

ACIAR Australian Centre for International Agricultural Research

AHB Asian Honeybee (*Apis cerana javana*)

AHBIC Australian Honeybee Industry Council

CCAHB Consultative Committee on Asian Honeybee Eradication

EADRA Emergency Animal Disease Response Agreement

EPPRD Emergency Plant Pest Response Deed

A. cerana = *Apis cerana*

A. mellifera = *Apis mellifera*

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Executive summary

This report reviews current scientific literature to determine what is known about the possible impacts of Asian honeybees (*Apis cerana*) on the Australian environment. The report was commissioned by the Australian Government (Department of Sustainability, Environment, Population, Water and Communities) to provide information for decision-makers and policy officers seeking to influence environmental biosecurity. Close to 100 references were reviewed and stored in an Endnote bibliographic database. Four key questions guided the collection of evidence to inform decision-making:

- 1) What do we know about *Apis cerana* – as a species, and in terms of their distribution, ecology, biology and incursion into Australia to date?
- 2) What do we know about other bees ecology, biology, etc?
- 3) What do we know about *Apis mellifera* impacts on Australian environments?
- 4) How do the species compare/interact and what can we learn about the comparison regarding potential impacts of *Apis cerana* on Australian environments?

Apis cerana is one of the species of social honeybees which demonstrate both individual and colony behaviour - a key to maximising invasion potential. Literature indicates that *Apis cerana* exhibits a great deal of 'plasticity' in its biology and ecology across its geographical range. Thus the biology and ecology attributed to *A. cerana* at one location in Asia does not mean that those attributes will apply to *A. cerana* at other locations. Most published literature on *Apis cerana* has been written in the context of it being an endemic (native) bee in the context of introduced *Apis mellifera* species. This may not apply to the genotype of *Apis cerana* currently inhabiting the Cairns region of far north Queensland. Literature reviewed covers *Apis cerana's* distribution, description, floral preferences, colony size, defense behaviours, flight patterns, swarming behaviours, nesting, parasitic mites and a brief overview of the current incursion.

Australian native bees differ significantly to the *Apis* honeybees in that they are mainly solitary bees. Australia also has 10 native species of stingless social bees. There is some evidence of potential environmental impacts arising from introductions of *Bombus terrestris* (bumble bees) and *Apis mellifera* (European honeybees).

The impact of exotic honeybees (*Apis mellifera* and *Bombus terrestris*) on the Australian environment is comparatively poorly understood in relation to their (positive) impact on productivity and agriculture. Feral honeybee impacts on Australian ecosystems are controversial but may include competition with native fauna for floral resources or nesting sites, inadequate pollination of native flora or undesirable pollination of exotic flora. Literature reviewed has been classified as describing interactions between honeybees and plants (floral resources), ii) interactions between honeybees and vertebrates and iii) interactions between honeybees and native bees.

There is very little (if any) published evidence of the environmental impact of *Apis cerana*. In Asia, where the species has been established for thousands of years, it is not labelled as an invasive species and therefore its environmental 'impact' has not been questioned. Given the invasion is relatively recent and there are no published studies of its environmental impact to date, actual impact of *A. cerana* on the Australian environment can therefore only be assessed given the (limited) data and careful observations of the Biosecurity Queensland Surveillance Manager and other experienced field officers. However, sufficient is known about Australian plant and animal communities to safely state that it is false to suggest *Apis cerana* will never have negative effects on

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nature conservation, just as it is false to suggest that they will have serious negative impacts in all circumstances.

Adherence to the precautionary principle around management of *Apis cerana* is recommended. Management recommendations include:

- establishing and maintaining *Apis cerana*-free and *A. cerana* -control areas with appropriate buffer zones;
- classifying natural habitat into *A. cerana* -free, *A. cerana* control or *A. cerana* affected areas for differential management of key native species;
- controlling *A. cerana* populations via baiting; and
- recording key observations of all *A. cerana* colonies/swarms in a centralised database.

One key area for future research is to determine where and when the risk of negative environmental impact from *Apis cerana* is highest such that limited resources are directed to areas of maximum return. Five recommendations for research priorities are suggested.

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Introduction

Research conducted in the United States, United Kingdom, Australia, South Africa, India and Brazil demonstrates that more than 120,000 species of plants, animals and microbes have successfully invaded and impacted native species in these countries. Many native species are threatened by competition and predation from invaders, while others are endangered by hybridization with invading species and/or major ecosystem changes caused by invasive species (Pimentel, McNair et al. 2001). In this context, it is critical to understand the potential impact of *Apis cerana* on Australian ecosystems and environments.

Objective

This study was funded by the Environmental Biosecurity section of the Department of Sustainability, Environment, Water, Population and Communities to determine what is known about *Apis cerana* and what is known about impacts of bees on the environment with a view to understanding potential impacts of *Apis cerana* on Australian environments. There are four key questions which guide the collection of evidence to inform decision-making in this area:

- 1) What do we know about *Apis cerana* – as a species, and in terms of their distribution, ecology, biology and incursion into Australia to date?
- 2) What do we know about other bees' ecology, biology, etc?
- 3) What do we know about *Apis mellifera* impacts on Australian environments?
- 4) How do the species compare/interact and what can we learn about the comparison regarding potential impacts on the Australian environment?

Methods

Fulfilling the functions of summarisation, classification, comparison and evaluation, the review provides the Department of Sustainability, Environment, Water, Population and Communities an overview of established findings, conflicting evidence and key gaps relating to environmental impacts of *Apis cerana*. There were four key components to the review; consult, search, analyse and report. Each is detailed briefly here. Although not strictly sequential, these phases represent the main tasks of this review.

Consult

Two key groups of stakeholders were consulted. The first group comprised the expert scientists and professionals (including the key Departmental liaison officer) with substantive background information and references and direct experience of the topic of the review. The second group were comprised of academics, researchers, government officers and other key agency staff who have written about or had past experience of, indirect experience or field-based experience with *Apis cerana* or environmental impacts. They were drawn from:

- Universities and research agencies (eg. University of Adelaide, CSIRO Entomology)
- State government agencies (eg. Biosecurity Queensland)
- Australian government agencies (eg. RIRDC)
- Independent consultants.

Search

Key search criteria were generated through an initial trawl of the literature and refined in consultation with CSIRO and SEWPAC. The scope and boundaries of the search (eg. international and national; reports, journal papers, book chapters, conference proceedings) were also generated and refined in consultation. The search phase involved collaboration and consultation with experts to establish the breadth and depth of the sample of publications reviewed. Following a 'snowball' sampling method, papers and references were sourced using structured search criteria as well as unstructured 'follow the trail' investigation. A database of key publications was established using Endnote bibliographic software. Rather than long summaries of each reference, an annotated bibliography of abstracts is provided.

The Endnote library comprises references (and attached electronic files) from a wide range of sources on key variables including:

- Authorship – government, industry, non-government organisation, science, community
- Publication type – academic, web-based, government
- Year/date
- Notes – overview, abstract, key citations
- Key words.

Analysis and reporting

The analysis began early and developed incrementally. Using Endnote, each reference was read, analysed and multi-coded under the key review questions. The review questions themselves were refined in consultation with SEWPAC staff as the review proceeded. The analysis was conducted by the principle consultant independently then reviewed by others to maintain rigour and validity.

The draft proposed structure was reviewed by SEWPAC to determine if there were any missing data sources or questions. The completed first draft of the review was then peer-reviewed for factual accuracy, logical consistency and coherence and further missing or recent data. The report is structured simply around the key review questions.

***Apis cerana* (Asian honeybee)**

There are about 20,000 species of bees belonging to the Superfamily *Apoidea*. *Apis* honeybees belong to a small sub-group of this superfamily comprising nine species and *Apis cerana* are one of five cavity-nesting species (Koeniger, Koeniger et al. 2010). Of critical importance to this review is the recognition of the genetic diversity present within *Apis cerana*. Initial studies on the species refer to 'races', 'strains' and 'sub-species' (Ruttner, 1988). More recent studies note that this species may be subject to 'cryptic speciation' and that its taxonomy is by no means resolved (Oldroyd and Wongsiri 2006). Three variants, once thought to be members of *Apis cerana*, are now recognized as distinct species (e.g. *Apis nigrocincta*, *Apis koschevnikovi* and *Apis nuluensis*) and other species may yet be recognized (Lo, Gloag et al. 2010). Therefore, to avoid confusion between current recognised variants of *Apis cerana* (eg. *indica*, *japonica*, *javana*) they will be referred to simply as 'genotypes' from particular locations.

Before continuing the description and analysis of *Apis cerana* from existing studies, a caveat should be introduced at this point. Care should be taken when interpreting aspects of the biology and ecology of *A. cerana* reported in the literature. This is simply because what is known about the bee comes from particular studies at particular places and times. That information clearly shows that *Apis cerana*, like *Apis mellifera*, exhibits a great deal of

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'plasticity' in its biology and ecology across its geographical range. Thus the biology and ecology attributed to *A. cerana* at one location in Asia does not mean that those attributes will apply to *A. cerana* at other locations. It also does not prove that current or future *A. cerana* genotypes that arrive in Australia will show 'general' *A. cerana* traits in Australian environments.

It has been claimed that *Apis cerana* (also known as Eastern honeybee, Asian honeybee, Asiatic hive bee, Mee Bee) is "the exact equivalent, in the Eastern part of the Old World, of its occidental sister species *A. mellifera*. It has an equally wide area of distribution with a similar capacity for a broad spectrum of adaptations" (Ruttner 1988). However, although a honey producer, it does not hoard large quantities of honey and it is therefore not the preferred species for honey production, compared with *Apis mellifera*. In Borneo, Koeniger et al (2010: 190) write that "collection of *Apis cerana* honey was regarded 'to be left for the boys because of the small amount of honey". More recently traditional bee keeping practices for *A. cerana* have been revived and have led to swarms being successfully trapped in 'gelodog' or rural hives before nectar flow and concentrated in smaller swarms after the nectar flow in the off season (Koeniger et al 2010). It is one of the species of social honeybees which demonstrate both individual and colony behaviour - a key to maximising invasion potential. Such flexibility enables them to withstand biotic resistance and to better match conditions in the receiving community (Moller 1996).

Distribution and description

Apis cerana is widely distributed throughout Asia, as far north as Japan and China, as far west as Iran and Afghanistan and south into India and Sri-Lanka (Ruttner 1988). At one stage its most south-eastern Asian range was west of the Wallace Line in Indonesia (Flores Island), however, that has been extended since a Java genotype of the species was introduced to New Guinea during the 1970s (Anderson, Annand et al. 2010) and now it is found throughout New Guinea (including Papua New Guinea), its offshore islands and in the Solomon Islands (Anderson 2010; Annand et al 2010).

The introduction of *A. mellifera* to Japan reduced the local *A. cerana* population to the point where "*A. cerana* is found only in remote mountainous areas, almost like a relic which could soon become 'an endangered species'" (Ruttner 1988:161). However, just the opposite occurred in parts of the Solomon Islands where the introduction of *A. cerana* led to the total extinction of the exotic *A. mellifera* populations on some islands (Anderson, 2010; Annand, 2010).

On average *Apis cerana* are smaller than *Apis mellifera*. *Apis cerana* is the third smallest of the nine species of honeybee (Koeniger et al 2010). However, it should be noted that there are some genotypes of *A. mellifera* that are smaller than medium-sized *A. cerana* genotypes and there is no significant difference between the smallest genotypes of both species (Ruttner 1988). However, the bigger *A. mellifera* genotypes considerably outsize even the largest *A. cerana* genotypes. *A. cerana* has distinctive stripes on its body compared to its European cousin *A. mellifera*. Figure 1 gives some indication of the relative size and appearance of each species.

Figure 1: *Apis mellifera* and *Apis cerana*



Photograph by Paul Zborowski, sourced from Biosecurity Queensland, Department of Employment Economic Development and Innovation

Ecology and biology

Competition and floral resources

There is relatively little written about the floral preferences of *A. cerana*. In 1958, Miyamoto noted that *A. cerana* in Japan visited a wider variety of plant species, including natives, compared to the limited floral preferences of *A. mellifera* (cited in Ruttner 1988). In a 1968 German study of honey from *A. cerana* and *A. mellifera* clear differences in the pollen spectrum were collected by the two species despite them operating at the same time and in the same vicinity (cited in Ruttner 1988). Some studies claim that *A. mellifera* is clearly dominant over *A. cerana* in common feeding locations (Sakagami 1959; Dhaliwal and Atwal 1970 cited in Ruttner 1988). Another, more recent study suggests the opposite. In the Solomon Islands, substantial losses of exotic *A. mellifera* honeybees were attributed to *A. cerana* robbing *A. mellifera* hives and increasing competition for floral resources (Anderson, Annand et al. 2010). As a recent ACIAR report noted: “we do not know what the consequences of competition from Asian hive bees would be [in Australia]. Would they, for example, pollinate the same flowers and crops as the European honeybee? The answer is probably not. The result would almost certainly be reduced pollination for some crops. Others might even gain. The topic needs urgent study” (Lee 1995: 6).

More widely accepted is that *A. cerana* does well in disturbed or extensively modified habitats. For example in Hong Kong, *A. cerana* visits 86% of plant species and pollinates so successfully as to maintain that island’s diverse flora (Corlett 2001 cited in Oldroyd and Wongsiri 2006). Of relevance to Australian environments, the Indica genotype of *Apis cerana* in Sri Lanka was observed foraging on *Eucalyptus robusta*: myrtaceae (River red gum) and it is cited as being an excellent source of honey (Punchihewa 1994).

In one study of *Apis mellifera* conducted in the Phillipines, researchers found that the endemic bees, *Apis cerana* and *Apis dorsata*, negatively affected the growth of *A. mellifera* colonies in a forest ecosystem by aggression and robbing of stores. However, this finding was not duplicated for colonies studied in industrial or agricultural areas. Rather, the population growth of *A. mellifera* in an agro-ecosystem was significantly higher than in the industrial or forest environments. The abundance of melliferous plants in the agro-ecosystem enhanced the population

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build-up of *A. mellifera*. They conclude that 'in spite of the diversity in a forest ecosystem, the exotic species *Apis mellifera* failed to exploit the nectar and pollen sources of most plant species. This indicates that *A. mellifera* did not adapt to natural forest conditions in the tropics (Manila-Fajardo and Cervancia 2003).

In nestmate recognition experiments, *A. cerana* was among the bee species that did not exhibit aggressive responses to the presence of other bees in their nests (Breed, Deng et al. 2007). These authors suggest that robbing of stored food may be more characteristic of *A. mellifera* than other species in the genus *Apis*. Similar reports appear in Ruttner's (1988) account of this species. In relation to *A. mellifera* robbing efforts, he writes that "no effective defensive reactions are developed in *A. cerana*" (Ruttner 1988: 137). Indeed not only can intruders pass unimpeded, but *A. cerana* bees inside a robbed colony were observed feeding the intruding *A. mellifera* robber bees.

Colony size and abundance

There is divergent evidence about the size of *Apis cerana* colonies. A recent report of a full sized colony described it as containing "about 1500g bees, 700g brood, about 4kg of honey and about 400g of cells filled with pollen" (Koeniger, Koeniger et al. 2010). Other reports cite 'usual' colony sizes of 1400-2000 bees or between 10 – 20,000 bees (Makhdzir and Osman 1980 cited in Ruttner 1988: 131; Okada 1985 cited in Ruttner 1988: 131). Colony size seems to depend on nest cavity availability (reported below).

Apis cerana tolerate a wide range of temperatures – from 5° C to 45° C: however when compared to *A. mellifera*, at 50° C, *A. cerana* survived for a much shorter time while at 5° C they equalled *A. mellifera* survival rates (Verma and Edwards 1971 cited in Ruttner 1988:130). There is evidence from Ussuria, Kashmir, Japan and China that *A. cerana* are active at lower temperatures compared to *A. mellifera* and that they are therefore more active earlier in the morning than *A. mellifera* and can start flying earlier in spring than *A. mellifera* (Ruttner 1988). However, it should be noted that these data "could be specific adaptations of certain ecotypes" (ibid p. 139) and may not be generalizable across whole species.

Defense behaviours

An important cautionary note should be observed from the outset about the behaviour of *Apis cerana*. Most science has been done on dead bees – with fewer descriptive studies of live specimens and very few experimental studies of comparative 'species characteristics'. Therefore it is not clear whether *Apis cerana* defense behaviour observed in the field at one location and point in time should be generalized to other times/places or for the species as a whole (Ruttner 1988).

Much has been written about colony defense behaviours and the consensus for *A. cerana* is that "it is generally reported as being mild, tolerant and timid" (Ruttner 1988) in the context of attacks from European genotypes of *A. mellifera*. However, there are some unique behaviours associated with this species associated with colony defense: a) abdomen shaking b) hissing (like a snake) in response to knocks or interference with the combs c) group defense via 'mob capture' of large wasps near the nest entrance, d) stinging behaviour. In Japan, Ono et al (1995 cited in Oldroyd and Wongsiri 2006: 201) noted one additional colony defense behaviour in response to attack from a hornet: recognition and removal of the marauding wasp pheromone before it has a chance to attract other hornets.

There is an important early paper by Sakagami which outlines the competition and interaction of *mellifera* and *cerana* honeybee species in observations at mixed colonies (Sakagami 1959). In Japan, the endemic *cerana* species was gradually replaced by *mellifera* with records of *cerana* extinction dating back to 1925 since *mellifera* were first introduced into that country in 1876. Japanese (alongside many other) apiarists preferred the introduced *mellifera* species given the ease with which they adapted to movable frames and their greater honey production.

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Sakagami summarises that "in general, *A. cerana* is more tolerant and less aggressive than *A. mellifera*" p. 67 On p. 65 he writes that "with respect to interspecific conflict [in mixed colonies *Apis mellifera*], usually took the dominant position in both aggressiveness and agility". He notes the superiority of [*mellifera*] species in terms of their larger colony size, strong fighting capacity and protection afforded by humans. Another difference between the two species was noted in terms of their foraging behaviour. Citing Hachinoe 1954, Sakagami writes: "[*mellifera*] have a tendency to concentrate their effort on a major nectar source whilst [*cerana*] tend to forage from numerous minor sources" p. 66. He also makes the point that under natural conditions, the species would interbreed very rarely, if at all.

Aligning with this assessment of less aggression of *A. cerana* compared to *A. mellifera* is evidence of their stinging behaviour. Oldroyd and Wongsiri wrote that "*A. cerana* are more likely to retreat inside the nest than to sting on the approach of a mammal" (2006:161). In one experiment, although *A. cerana* do sometimes attack an intruder (an artificial mouse made of felt) – afterwards no stings were detected in the felt – whereas *A. mellifera* stings were extensive on the same target. Moreover, the sting of an *A. cerana* worker bee contains about half the quantity of stinging material (isopentyl acetate) compared to those of *A. mellifera* worker bee stings. However it has been reported that *A. cerana* stings have an effect for considerably longer than *A. mellifera* stings (pers. comm Wim de Jong May 24 2011). Finally, *A. cerana* appears to have the least well developed barbs on the sting lancet compared to all other *Apis* species' barbs (Ruttner 1988).

Flight patterns and swarming

A. cerana bee flights are reported to be similar to fly flights in that they are rapid and unpredictable compared to *A. mellifera* flight patterns. There is also some unpublished evidence that *A. cerana* colonies in hives demonstrated 5.5 times as much flight activity relative to the number of bees in a colony compared to *A. mellifera* (Ruttner, 1988:138). However, they tend not to fly far from their nests to forage; one source claims that this distance can be as far as 750 metres but that 300 metres is more typical (Punchihewa 1994).

Swarming activity associated with *A. cerana* reproduction is reported differently in different countries. In Japan, Tokuda recorded one, two or three swarms per colony per year, while researchers in Pakistan recorded an average of eight swarms per year (cited in Ruttner 1988:144). Koeniger et al (2010: 63) report that in "tropical conditions swarms can survive and travel for several weeks...[however] longer periods of nectar scarcity or extended periods of rain will put the survival of a swarm at risk". In Taiwan, Fen Tsung-Deh reported regular seasonal migration swarms by *A. cerana* between humid mountain areas and flatter areas (Fen Tsung-Deh 1952 in Ruttner 1988: 146). In Australia, extensive field observation of the limited incursions to date indicate that there may be a difference in swarming behaviour depending on whether they are a) reproductive swarms (1-2 per year) or b) absconding swarms (up to 7 per year). There may also be a difference in swarming behaviour depending on whether *A. cerana* is in colonization ("bunker down after moving in") or invasion mode ("up stakes and spreading out") (de Jong, pers. comm. 24 May 2011). Swarms of *A. cerana* who abscond (ie desert their nests) generally do so in response to a shortage in floral resources, an attack or approach by predator/s or disease outbreak e.g. from wax moths. Absconding behaviour is reported differently in different countries – with more frequent reports of absconces from Thailand and in temperate Japan and less frequent reports in S. Asia (Ruttner 1988).

Nesting

As a species of cavity-dwelling bees, *Apis cerana* colonies nest in hollow trees, caves, rock-clefts, walls, roof spaces and rafters – as well as nest cavities provided by birds, small mammals and tree-dwelling reptile species. In Sri Lanka, it was thought that *Apis cerana* require fully-enclosed cavities in which to nest (Punchihewa 1994), however this is not observed in other places. It is widely thought that *A. cerana* occupy smaller nest cavities than *A. mellifera* given their smaller physical size and colony size. *Apis cerana* occupy smaller hives than *A. mellifera* when they are farmed and there is evidence that *A. cerana* colonies fail in standard size hives (Pandey 1977 cited

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in Ruttner 1988). However, in natural environments, *A. cerana* build nests in cavities with volumes as small as 4.5 litres to as large as 97 litres (Inoue et al 1990 cited in Olroyd and Wongsiri 2006: 153). In one study, *A. cerana* was found in a tree cavity with a diameter of 12 cm (Inoue, Adri and Salmah 1990 cited in Olroyd and Wongsiri 2006: 153). Unlike other cavity-nesting bees, cavity entrances of *A. cerana* nests vary widely (from 2-100cm²) and are often found within 1-2 m off ground level (Inoue et al 1990; Seeley et al 1982 cited in Olroyd and Wongsiri 2006: 154).

A. cerana are one of the cavity-nesting species which thermoregulate nest temperatures. Where external ambient temperatures may vary between 12° C -36° C, this bee species is able to maintain the brood nest temperature in the range of 33° C -35.5° C. In particularly hot weather, *A. cerana* will use evaporative cooling mechanisms, collect water and cluster outside the nest. In particularly cold weather, *A. cerana* have been observed using metabolic heat to warm brood nests.

There is some evidence (well documented in Ruttner 1988) of *A. cerana* routinely 'dismantling' old combs in nests in order to build new cells upon it. Arguably, this may contribute to more hygienic practices at the comb-site, but less as the old wax debris accumulates on the bottom of the hive and provides a suitable medium for wax moths (Ruttner 1988).

Mites¹

From extensive DNA matches, Denis Anderson of CSIRO demonstrated in a recent RIRDC workshop that parasitic bee mites are tightly matched in an evolutionary sense to their bee hosts (Rural Industries Research and Development Corporation and Horticulture Australia Limited 2010). Based upon molecular work conducted by Anderson and others (Anderson 1994; Anderson and Trueman 2000; Navajas, Anderson et al. 2009), it is now accepted that host transfers from Asian species to *A. mellifera* are extremely rare. Transfers that have occurred took place in the past 40-100 years (Oldroyd and Wongsiri 2006:193). However a recent CSIRO report for the Department of Agriculture, Fisheries and Forestry notes that a transfer occurred recently in 2008 (Anderson 2008).

Species of *A. cerana*, *A. dorsata*, *A. laboriosa*, *A. florea* and *A. adreniformis* are the primary host of three different genus of mites, *Tropilaelaps*, *Euvarroa* and *Varroa*. Mites in the genus *Tropilaelaps* are parasites of the giant honeybees of Asia (*A. dorsata* and *A. laboriosa*) (Anderson and Morgan 2007). Some are occasionally observed inside *A. cerana* colonies in Asia (Ruttner 1988; Otis and Kralj, 2001). However, except for one rare instance in Asia (Anderson and Morgan 2007) there is no other evidence that these reproduce on *A. cerana* brood (Otis and Kralj 2001). Mites in the *Euvarroa* genus are hosted by *A. florea* and *A. adreniformis*.

A. cerana is host to three different kinds of *Varroa* mites – including *V. jacobsoni*, *V. underwoodi* and *V. destructor* depending on the genotype of *A. cerana* (Anderson and Trueman 2000). So far only genotypes of *Apis cerana* from northeast mainland Asia and the Japan region carry the forms of *Varroa destructor* which are so damaging to *A. mellifera* globally. The Java genotype of *Apis cerana* carries mites that have long been known to be harmless to *Apis mellifera*. However, in 2008 a harmful form of the mite was detected in Papua New Guinea (Anderson, 2008). This mite did not accompany the Java genotype of *Apis cerana* into the Solomon Islands (Anderson, Annand et al. 2010). The bee in the Solomon Islands carries a harmless form of the Java genotype of *V. jacobsoni*.

Apis cerana can effectively remove *Varroa jacobsoni* through grooming behaviour consisting of self-cleaning, grooming dance, nestmate cleaning, and group cleaning. *Apis cerana* worker bees can also rapidly and effectively remove *Varroa jacobsoni* mites from the brood. However, *Apis mellifera* does not demonstrate such a high level of

¹ This section was co-authored by Denis Anderson of CSIRO.

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cleaning frequency and generally fail to remove significant numbers of mites from adult bees and brood (Peng, Fang et al. 1987).

Incursions

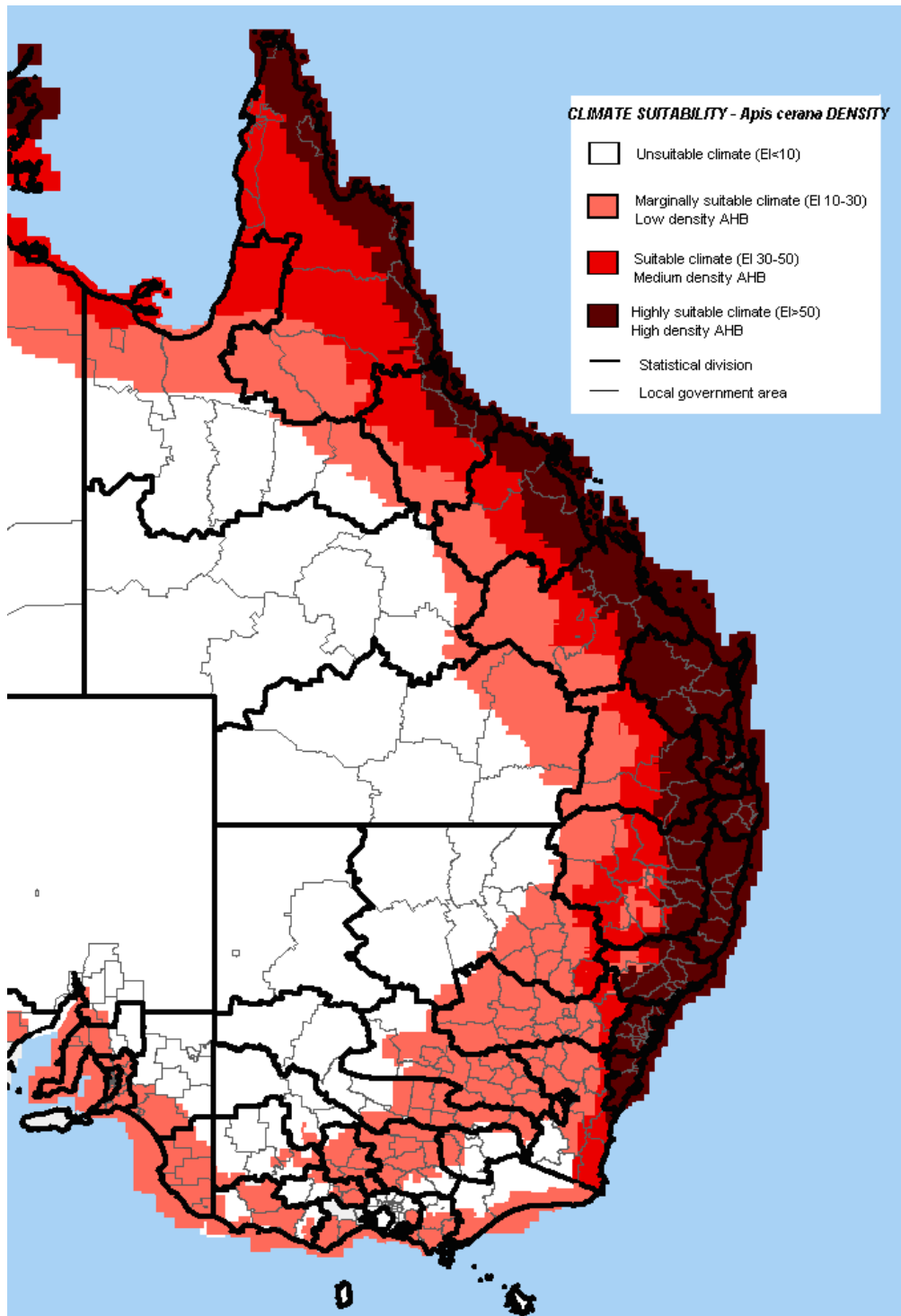
Until 2007 the only non-native resident species of honeybee in Australia was *Apis mellifera*, the common (European) honeybee. There have been specific instances of potential incursions of *A. cerana*, in 1995, 1998, 1999, 2002, 2004, 2005 and 2007 (Barry, Cook et al. 2010). These arrivals came on ships from Papua New Guinea and were detected and destroyed at Australian seaports. This indicates that more arrivals can be expected from that region in the future, some of which may carry *Varroa* mites. However, there have only been two major incursions of *A. cerana* into Australia (Anderson, pers. comm. 13 May 2011). The first, in 1998, was at Darwin. Only a single colony was found and destroyed, and no colonies have been found and reported since. This lone colony was later identified by CSIRO as the Java genotype of *A. cerana*. The second incursion was at Cairns in May 2007. This was also of the Java genotype of *A. cerana*. Since 2007 more than 390 detected nests or swarms of the bee have been detected and destroyed in the Cairns region, and all have been free of parasitic mites (de Jong 2011).

The science of where the Java genotype of *A. cerana* may spread in Australia is still under development, but initial CLIMEX modelling (See Figure 2) indicates that it could naturalise to tropical and coastal regions in nearly all parts of eastern Australia, and RIRDC sources place no east-west division limits (Ryan 2010). There are two features of Australian environments which may inhibit or limit the range of *Apis cerana*: i) the high temperatures and arid landscape of inland deserts which provides neither sufficient floral resources to sustain new colonies or water resources to cool them and ii) the extreme low temperatures above the snow-belt in high country in winter for similar reasons (Anderson, pers. comm. 13 May 2011). However, Anderson reports that this genotype exists well in the arid centre of Timor and in the western highlands of Irian Jaya where a permanent glacier exists (Anderson, pers. comm. 13 May 2011).

As noted in a 2010 report of social and economic impacts of *Apis cerana*, the CLIMEX suitability map in Figure 2 was drawn on the basis of invasion by the tropical providence of the Java genotype of this species. Cooler southern states of Australia are currently relatively safe from the recent introduction of *Apis cerana* for as long as natural selection of populations better adapted to cooler climates does not occur. If swarms of the current introduction became established, it would be very difficult to distinguish these from any subsequent introductions of cold-tolerant *Apis cerana* strains (Goswami and Antony 2010).

In April 2011, the Senate Rural Affairs and Transport References Committee concluded that “there is significant uncertainty as to the potential extent of the spread of the Asian honey bee in Australia, and the associated environmental, economic and social costs” (Senate Rural Affairs and Transport References Committee 2011).

Figure 2: Map of expected density of *Apis cerana* (Java strain) based on climate using CLIMEX model.



CLIMEX model image supplied by Animal Health Surveillance, Biosecurity Queensland

The Asian Honeybee National Management Group formed the view in January 2011 that eradication of the Asian honeybee is no longer technically feasible (Australian Government 2011). However, in May 2011, the decision was made to renew management efforts.

Other bee species in Australia

Aside from the recent incursion of *Apis cerana*, there are both native and introduced bees in Australia. This section (briefly) reviews what we know about these other bee species before turning to their specific environmental impacts. Note here that there is more written about introduced bee species than there is written about native species. The focus here is to provide basic descriptive information that will assist the comparison of these species with *Apis cerana* and how they may impact Australian environments.

Australian native bees

There are more than 1,500 species of Australian native bees which differ significantly to the *Apis* bees of interest here in that they are mainly solitary bees which raise their young in burrows in the ground or in tiny hollows in timber. However, Australia also has 10 native species of stingless social bees (genera *Trigona* and *Austroplebeia*). Honey from these bees is an important bush food and has a critical place in Australia's cultural and environmental history. Australian native bees can be black, yellow, red, metallic green and multi-coloured. The smallest native bee is the *Quasihesma* bee and is less than 2 mm long from Cape York. Australia's largest native bee is the Great Carpenter Bee of the tropical north and northern NSW. It is up to 24 mm long (Australian Native Bee Research Centre 2011). Paine has examined the reproductive success of two of these native bees (*Megachile* sp. 323 and *Hylaeus alcyoneus*) as part of a study to determine the impact of *Apis mellifera* (Paine 2004a; Paine 2004b; Paine and Roberts 2005). This is reported below.

As critical pollinators native bees play an important part in protecting Australian native ecosystems. Australian Blue Banded Bees (*Amegilla*) is one of two native bee species capable of a special type of pollination behaviour called 'buzz pollination'. In some plants, the pollen is trapped inside tiny capsules in the centre of the flower. The blue banded bee curls around the flower and rapidly vibrates its flight muscles, causing the pollen to emanate from the capsules. *Apis mellifera* honeybees are not able to buzz pollinate flowers. Australian native social stingless bees (*Trigona*) are successfully used for pollination of crops such as macadamias, mangoes, watermelons and lychees in Queensland. They are particularly efficient pollinators of macadamias. Research has shown that the native stingless bees mainly collect pollen from these flowers, whilst *Apis mellifera* honeybees mainly collect nectar. It is reported that native stingless bees are far more attracted to the macadamia flowers than are *Apis* honeybees (Dollin 2011).

Bombus terrestris (bumble bee)

Bumble bees (*Bombus terrestris*) were first detected in Tasmania in February 1992 and are known to have visited both introduced and native plant species there (Semmens 1996). In 2002 a study showed that *B. terrestris* is established in remote parts of Tasmania and is not dependent on introduced garden plants (Hingston, Marsden-Smedley et al. 2002). The same authors concluded that it is likely that *B. terrestris* will form feral populations on the mainland of Australia given their invasion record. They also suggested that *B. terrestris* are likely to negatively impact native animals and plants, and have the potential to enhance seed production in weeds (Hingston, Marsden-Smedley et al. 2002). Four years later, Hingston reiterated his finding that *B. terrestris* has extensively invaded Tasmanian native vegetation being found at 42 locations in 10 National Parks and 38 locations within the Tasmanian Wilderness World Heritage Area. On the basis of this evidence, he concluded that *B. terrestris* would also invade native vegetation in non-arid temperate regions of the Australian mainland, if it is introduced there (Hingston 2006).

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***Apis mellifera* (European honeybee)**

The European honeybee, *Apis mellifera*, was introduced to Australia between 1810 and the early 1820s (Oldroyd, Thexton et al. 1997; Simpson, Gross et al. 2005) and is now widespread both as a result of the managed honeybee industry and of feral populations. Feral colonies can reach extremely high densities in some Australian environments. For example, Oldroyd et al. (1994) estimated that there were 77.1 colonies/km² in the riparian woodland of Wyperfeld National Park in northwest Victoria. (Oldroyd, Thexton et al. 1997).

To determine the potential impact of *Apis mellifera* on biodiversity and conservation, it is important to understand the density of wild honeybee colonies in relation to the managed population. Although there is some evidence on the density of feral honeybee colonies (Schneider et al. 2004 cited in Moritz 2007; (Oldroyd, Thexton et al. 1997) reliable density estimates in endemic wild populations worldwide are deficient. This is unsurprising given that wild *A. mellifera* colonies (nests) are usually very hard to detect making actual population size estimates difficult. Moritz et al writes that "the area covered by a population of *A. mellifera* can be extremely large. The mating range of queens and drones can exceed 80 km² (Ruttner and Ruttner 1972), an area far too large to reliably search for honeybee colonies." (Moritz, Kraus et al. 2007).

Environmental impacts of exotic bees

The impact of exotic honeybees (*Apis mellifera* and *Bombus terrestris*) on the Australian environment is comparatively poorly understood in relation to their (positive) impact on productivity and agriculture. More has been written about *Apis mellifera*. However, the environmental impact of another exotic bee the Large Earth Bumblebee – *Bombus terrestris* is also reported where appropriate. Both *Apis mellifera* and *Bombus terrestris* have been listed as key threatening processes to biodiversity in NSW (in 2002 and 2004 respectively). In 2000, Victoria listed *B terrestris* as a potentially threatening process (Gross, Gorrell et al. 2010). Feral honeybee impacts on Australian ecosystems are controversial but may include competition with native fauna for floral resources or nesting sites, inadequate pollination of native flora or undesirable pollination of exotic flora (Oldroyd 1998). Each of these is detailed further below and is structured as i) interactions between honeybees and plants (floral resources), ii) interactions between honeybees and vertebrates and iii) interactions between honeybees and native bees.

Interactions between honeybees and plants

Pollination and reproduction of native plants

European honeybees distinctive biology (adapted to European plant species) may cause patterns of native plant pollination that differ from Australian native pollinators. In general, it is safe to state that relatively little is known about this topic given the number of native plant species and the paucity of experimental studies in this area. In a study of native bush in Western Australia's northern sand plain (known to be rich in plant biodiversity), honeybees used 30% of 413 plant species available. Authors concluded that *Apis mellifera* impact on *Dryandra sessilis* is largely unknown although there are possible negative effects on the pollination of this Western Australian native post-fire seed regenerator species (Wills, Lyons et al. 1990).

In his controversially-named 1990 article, Pyke cites three possible scenarios:

- 1) honeybees in competition with native pollinators could lead to pollination and plant reproduction below natural levels
- 2) honeybees in addition to native pollinators could lead to pollination and plant reproduction above natural levels
- 3) honeybees could alter native pollination, pollen movement and plant reproduction through visiting different numbers of flowers per plant or flying different distances between plants thereby altering native pollination (Pyke 1990).

In sum, Pyke cites 'prima facie' evidence that honeybees have a deleterious effect on native plants and animals. He then cites actual evidence of negative impact for the following species: *Leptospermum squarosum*, *Hakea teretifolia*, *Callistemon rugulosus*, *Banksia ericifolia*, *Blandfordia nobilis*, and *Correa reflexa* based on Pyke and Balzer (1985) and Sugden and Pyke cited in Pyke (1990). The evidence cited is based on i) displacement of native pollinators by *A. mellifera* and ii) *A. mellifera* not triggering pollination and plant reproduction mechanisms on flowers visited.

Changes in the numbers and behaviour of native pollinators have the potential to disrupt the pollination of plants, reduce seed production, and potentially threaten the long-term survival of the plants. In an important study, Paton demonstrated that honeybee foragers are less efficient pollinators of *Correa* and *Callistemon* than native birds. He

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then questions whether honeybees provide pollination services that are comparable to those provided by the native fauna that they have displaced... and if not whether the plants experience reduced levels of seed production (Paton 1993). Note here that changes in the number and/or behaviour of native pollinators due to the presence of exotic bee pollinators does not always imply a competitive relationship amongst pollinators (Paini 2004b). Note also that a demonstration of potential competition for floral resources does not necessarily result in a reduction in reproductive success of native pollinators, or a long term decline in their numbers (Oldroyd, Thexton et al. 1997; Paini 2004b).

For native plant reproduction, there is more evidence of a negative impact from *Apis mellifera* than a positive impact. In one comparative study of honeybee and native bee pollination of the *Melastomana affine* in tropical montane rainforest systems in north Queensland, the authors concluded that honeybees were poor pollinators of *Melastomana affine* compared with native bees (Gross and Mackay 1998). Honeybees placed significantly less pollen on stigmas than native bees and honeybees actively removed pollen from stigmas. As a consequence reproduction in terms of fruit-set and seed-set was less likely.

A caveat should be introduced here: Butz-Huryn points out that plant abundance and reproduction is not solely regulated by factors influencing pollination; it is also affected by seed dispersal and predation, the germination environment, and herbivory. While gene flow in plant populations is dependent upon pollen flow, it is ultimately governed by factors that affect seed dispersal and plant growth (Butz Huryn 1997).

Not all studies illustrate that honeybees diminish pollination of native species. In one study of the endemic shrub *Dillwynia juniperina* found in the Northern Tablelands of New South Wales, two species of native bees (*Leioproctus* sp. 1 and *Lasioglossum* sp.) and the introduced honeybee, *Apis mellifera* L., were the most common visitors to flowers (Gross 2001). That study found that a) native bees were never the dominant pollinator, b) native bee presence on individual shrubs is negatively correlated with the presence of honeybees at the same shrubs, and c) extrapolation of visitation data showed that native bees alone could adequately service flowers in some years at some sites while at other times introduced honeybees may be necessary to augment pollination services.

There may be other beneficial interactions between *Apis mellifera* and native plants. Because *Apis mellifera* are polyleges (generalist pollen and nectar collectors) in cases where native plants may have lost their endemic pollinators (perhaps due to land clearing, fires or extinctions) honeybees may provide a pollination service and enable those plants to set seed. Paton (1993) cites the example of *Orthrosanthus multiflorus* flowers that bloom for only one day. It was observed that flowers were visited as often as 50 times by honeybees but in the same period native bees often failed to visit all the flowers and may not have visited any flowers on some days (Paton 1993). In this case *Apis mellifera* clearly lead to pollination and plant reproduction above 'natural levels': they are successful pollinators – but may not be discriminating ones.

Pollination and reproduction of weed species

It was previously thought that because weeds are not exclusively dependent on bees for pollination and because bees are generalist pollinators, although honeybee pollination of weeds may be substantial, it was not a significant risk given the number and variety of other capable pollinators (Butz Huryn and Moller 1995 cited in Butz-Huryn 1997: 284). However, more recent studies highlight the success of *Apis mellifera* in pollinating agricultural and environmental weeds. One Tasmanian study examined how *Apis mellifera* and *Bombus terrestris* affect the pollination of *Lupinus arboreus*, an invasive, nitrogen-fixing shrub, rarely visited by native pollinators. Reproductive success was positively related to the visitation rates of both exotic bee species. (Stout, Kells et al. 2002). Other Tasmanian studies of *Bombus terrestris* and *Apis mellifera* demonstrated the potential of those species to exacerbate the spread of the invasive scotch broom whose flowers have to be tripped to effect seed set.

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Authors concluded that the impacts of these introduced pollinators in terms of the potential for promoting range expansion in pollinator-limited 'sleeper weeds' remains a substantial risk (Simpson, Gross et al. 2005; Stokes, Buckley et al. 2006). In the most recent Australian study, Gross and her colleagues examined the reproductive ecology of *Lippia* (*Phyla canescens*) a South American weed species. They found that not only was *Apis mellifera* nearly 10 times more abundant than other floral visitors and pollinators, but that within the study site, almost 500 000 seeds per hectare would be produced annually as a result of honeybee pollination (Gross, Gorrell et al. 2010).

In support of Anderson's observation that exotic bees are better suited to pollinate exotic plants, Gross writes that "in ecosystems, where honeybees have been introduced, they are often poor pollinators of native species with which they do not share a co-evolved history" (Gross, Gorrell et al. 2010). Conversely, many other introduced plant species in Australia benefit from pollination services rendered by the introduced honeybee (ibid: 370). However, it is important to carefully examine any and all assumptions before drawing conclusions about likely impacts of *Apis cerana* in Australian environments. Critically, a shared evolutionary history between bees and plants is not an essential prerequisite in order for honeybees to be successful pollinators. Pollination is not a specialist activity. Most plant species allow visits by taxonomically diverse animals even in semi-specialized flowers and tightly specialized relationships are rare (Faegri and van der Pijl 1979, Baker 1963, Waser et al. 1996 cited in Butz-Huryn 1997: 276).

In an excellent review of literature on the ecological impacts of *Apis mellifera*, Butz-Huryn (1997) summarises that:

- Honeybees do not physically damage plants
- they are also unlikely to increase hybridization of native flora
- honeybees often use less than a third of available flowering species, and substantially fewer species are used intensively
- foraging by honeybees, therefore, will have variable impacts depending on the plants used, and consequently on native fauna that use the same resources.

Interactions between honeybees and vertebrates

Similar to interactions between honeybees and plants, there are three possible scenarios for the relationship of honeybees and vertebrates:

- 1) an adverse effect of honeybees in competition with vertebrates
- 2) a beneficial effect of honeybees on vertebrates
- 3) no effect or variable impact of honeybees on vertebrate resources or behaviours.

Anderson (1989: 300) concludes that *Apis mellifera* is a potential threat to native pollen-dependent and nectar-dependent fauna because they are "prodigiously active and have a highly controlled and successful social system". In 2002 NSW listed competition between feral honeybees and native wildlife as a key threatening process to biodiversity under the NSW Threatened Species Conservation Act (Gross, Gorrell et al. 2010). Most of these adverse impacts appear in the literature in relation to their impacts on birds. In 2007, CSIRO concluded that "no researcher has investigated the impact of honeybees on native marsupial pollinators (CSIRO 2007).

In 1993, Paton demonstrated that New Holland honeyeaters (*Phylidonyris novaehollandiae*) travelled further to collect nectar from *C. rugulosus*, altered their feeding behaviour and increased the size of their territories after experimental introduction of beehives (Paton 1993). Where honeybees are absent, honeyeaters visited all flowers equally. However, when honeybees are working the same flowers, he found that birds visited flowers that are deep within the canopy of the plant and concentrated their foraging activity at the flowers used least by

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honeybees. This suggests that honeybees competitively exclude native birds from some flowers. Earlier papers cited by the same author reveal competition between birds and honeybees for floral resources in relation to a range of bird-pollinated plants. He noted that honeybees sometimes removed more pollen from native *Correa reflexa*, *Eucalyptus remota*, *Adenanthos terminalis*, and nectar from the scarlet bottlebrush, *Callistemon rugulosus*, and *A. terminalis*, than was removed by birds which represented more than 90% of the nectar and/or pollen produced by some plants (Paton 1985, 1990 cited in Paton 1993).

However, in later papers he suggests that when nectar is abundant, honeybee competition with native fauna is low. This is evident when even near apiaries significant quantities of nectar remained unexploited in flowers, suggesting that honeybees are not threatening native flower visiting fauna in times of 'plenty'. The abundance of nectar in flowers at these times was not caused by an increase in secretion rates but by low visitation rates from native fauna, particularly nectar-feeding birds (Paton 2008).

Nesting hollows and cavities

Feral bee colonies' nests and regent parrot nest sites overlap. However, in a study of red gum / black box woodlands in Wyperfeld National Park in Victoria (Oldroyd, Lawler et al. 1994), it was reported that there is no significant interaction between the species' choices of site, furthermore 52% of bee nests were in cavities unsuitable for regent parrots. Feral honeybee colony density was measured at 77.1 colonies per square km which is considerably higher than reported elsewhere. Average occupation rate of bee nests was 1.3% of trees and 0.7% of available hollows.

There have been two cases reported where nests of the white-tailed cockatoo failed as a result of swarming honeybees (Saunders 1979). However, although honeybee competition with native vertebrates for nesting sites is a conservation concern, experimental evidence has not shown competition for nesting sites between honeybees and native fauna (Butz-Huryn 1997: 285 citing Matthews 1984, Robertson et al. 1987 and Pyke 1990). It appears that there are other factors that influence nest-site occupation more than honeybees. Writing about the Nelson area of New Zealand, Butz-Huryn notes that while tree hollows could theoretically be used by both birds and honeybees, in fact predation by introduced rats and stoats is the main reason for the ongoing declines of New Zealand's cavity-nesting birds (Butz-Huryn 1997: 285). Similar hypotheses could be generated in relation to Australian nesting hollows and cavities and their occupants' relationship with feral cats, foxes, other predators and other threatening processes.

Interactions between honeybees and other native bees

As a result of widespread colonies of *Apis mellifera*, Australian native bees now share most of their sources of nectar and pollen with honeybees. It is hypothesized that competition increases between *Apis mellifera* and native bee species as many are of a similar size and require the same pollen and nectar resources for their progeny (Paini, Williams et al. 2005). This potential competition is explored further here.

One important group of Australian native flower-visiting insects are native bees (*Apoidea*) introduced earlier. As noted above, many of Australia's native bees are smaller than the introduced honeybee and are not social (Michener 1970, 1979 cited in Paton 1993). Their activity at flowers is usually concentrated in the middle of the day, when ambient temperatures are highest. In an early reference to an unpublished study in Royal National Park near Sydney, Anderson notes that *Apis mellifera* forage earlier and later in the day compared to native insects and that they outnumber endemic insect species (Anderson 1989). This difference in foraging activity gives the exotic honeybees an advantage in any competitive interaction, particularly if floral resources are present in the morning (Paton 1993).

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There is significant overlap in the floral resources used by honeybees and native bees indicating the potential for inter-species competition. In a Western Australian study of *Apis mellifera* foraging behaviour, of 51 species used by honeybees, 70% of those were also foraged by native bees (Wills, Lyons et al. 1990). This study indicates that native bees and *Apis mellifera* co-exist. However, authors commented that "other species of native bee which may have formerly inhabited this region may have already been displaced due to the effects of either direct or indirect competition with *Apis mellifera*". (Ibid, p.170).

Gross' earlier work on the effect of *Apis mellifera* on native bee visitation and fruit-set in *Dillwynia juniperina* suggests that native bee presence on individual shrubs is negatively correlated with the presence of honeybees at the same shrubs. In other words, honeybees could have a negative impact on native bees given that they were less likely to forage at bushes where honeybees were present (Gross 2001). This finding was replicated in the 1998 study of *Melastoma affine* where it was found that in "91% of interactions between honeybees and native bees, native bees were disturbed from foraging at flowers by honeybees" (Gross and Mackay 1998).

In subsequent Australian work Dean Paini reviewed the literature on inter-species competition between native and introduced bees for floral resources (pollen and nectar) as part of his PhD thesis. He concluded that long-term survival of Australian native bee species in terms of their fecundity or population density requires further empirical assessment (Paini 2004a; Paini 2004b). Paini conducted two experiments on the impact of *Apis mellifera* on native bee species. One showed that *Apis mellifera* negatively impacted completed nests of the native honeybee (*Hylaeus alcyoneus*). This mirrors a North American study which showed that when honeybees are present, native bee reproductive success is reduced (Thomson 2004). These results provide evidence that "*Apis mellifera* competitively suppresses a native social bee known to be an important pollinator, with the potential for cascading effects on native plant communities" (Thompson (2004:458). She also notes that although competitive interactions between invasive and native species are considered among the most important mechanisms driving invasion dynamics, such interactions are in general poorly understood. Other American studies demonstrate that a range of native bees switch to less profitable resources when honeybees are abundant at the richest patches of flowers (e.g., Roubik 1978,1980,1982, Schaffer et al. 1979, 1983, Ginsberg 1983 cited in Paton (1993: 95).

Back in Australia, Paini's second experimental study showed no impact from *Apis mellifera* on the fecundity of a species of native solitary bee (*Megachile*). Paini demonstrated that although a large resource overlap occurred between the two species, there was no significant change in the reproductive success of the native bee. However, there are two mitigating circumstances which may have affected experimental conditions.:

- i) The short term (four week period) during which the experiment took place may not truly reflect the result of the long term presence of honeybees.
- ii) Weather conditions were hot during this period and *Apis mellifera* spent a lot of time cooling their nests rather than foraging.

Paini et al. conclude that the native bee, being better adapted to the high summer temperatures experienced during the period of this experiment, may be able to withstand honeybee competition (Paini, Williams et al. 2005).

In the most recent review of the widespread impacts of exotic bees on native bees worldwide, Stout and Morales (2009) summarise these into five major factors. The first of these is competition for floral resources which can be broken into a) resource niche breadth and overlap; b) comparative efficiency in resource acquisition and c) resource depletion. Other major factors implicated in the impact of exotic bees on native bees include:

- Competition for bee nesting sites

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- Transmission of pathogens
- Reproductive disruption and hybridization
- Modification of native plant community structures (Stout and Morales 2009).

The result of all this analysis is that there is inconclusive evidence of the relationship between honeybees and native bees. This is not dissimilar to the evidence found in Paine's initial review in 2004 and mirrors the interactions between honeybees and plants or honeybees and vertebrates. One response is provided by the Committee on the Status of Pollinators in North America, National Research Council, who recommended that more research is required on all native bees but especially on solitary species and specialists (Stout and Morales 2009). This has direct application to Australian native bees, many of which are poorly described or understood.

Discussion: environmental impacts of Asian honeybees

There is very little (if any) published evidence of the environmental impact of *Apis cerana*. In Asia, where the species has been established for thousands of years, it is not labelled as an invasive species and therefore its environmental 'impact' has not been questioned. A recap of what we have deduced so far is useful here. This section starts with a summary of what we know about *Apis cerana* compared to other species, then summarises the environmental impacts of exotic bees. It then reviews what others have asserted will be the impacts and presents limited evidence of observed impacts before introducing a section on hypotheses/questions requiring clarification. Finally recommendations for management and research are suggested.

Summary of differences: *Apis cerana* and other bee species

Apis cerana is one of the species of social honeybees which demonstrate both individual and colony behaviour - a key to maximising invasion potential. Such flexibility enables them to break down biotic resistance and better match conditions in the receiving community. *A. cerana* does well in disturbed or extensively modified habitats. *Apis cerana* tolerate a wide range of temperatures - from 5° C to 45° C and are better at lower temperatures than *Apis mellifera*. This provides them with a competitive advantage - foraging earlier in the day and starting earlier in the spring season compared with *Apis mellifera*. However, it is likely that this evidence comes from the japonica strain and not the javana strain of the species. *Apis cerana* are excellent foragers and tend to forage from numerous minor sources compared with *A. mellifera* which have a tendency to concentrate their effort on a major nectar source (ie monocultural crops). They also tend not to rob stored food from other colonies - a behaviour more characteristic of *A. mellifera* than other species in the genus *Apis*. *A. cerana* is generally reported as being mild, tolerant and timid in the context of attacks from *A. mellifera*.

They conserve energy, build smaller nests, fly more, more erratically, and over shorter distances than *A. mellifera*. They also swarm differently depending on whether they are a) reproductive swarms (1-2 per year) or b) absconding swarms (up to 7 per year). Swarms of *A. cerana* who abscond (ie desert their nests) generally do so in response to a shortage in floral resources, an attack or approach by predator/s or disease outbreak e.g. from wax moths. *A. cerana* build nests in cavities with volumes as small as 4.5 litres to as large as 97 litres with cavity entrances ranging from 2-100cm² and are often found within 1-2 m off ground level. This apparent non-specialisation provides them with a wide range of potential nest sites. *A. cerana* routinely dismantle old combs in nests in order to build new cells upon them which contributes to good hygiene practices in relation to mites. *Apis cerana* very effectively remove *Varroa jacobsoni* mites

It is timely here to reiterate two caveats before finishing this overview of *Apis cerana* with an observation. First, simply because one or more researchers have collected evidence of *A. cerana* biology and ecology does not provide conclusive proof of that characteristic or behaviour trait of current or future *A. cerana* strains in Australian environments. Second, it appears that most research on *Apis cerana* has been done on northern strains and not the javana strain more typical of the tropics. Last - there are no published studies comparing *A. cerana* with Australian native bee species or with *Bombus terrestris*. What literature exists comparing *A. cerana* with *A. mellifera* is written from the point of view of the former being a native species and the latter an introduced or exotic bee.

Summary of environmental impacts of exotic bees

Exotic bees interact with Australian plants, vertebrates and native bees. Most studies are specific examinations of a particular species at a particular place and point in time and some of these are presented above. There have been three excellent literature reviews on this topic. These are summarized here in chronological order.

Paton's (1996) study of the impact of feral and managed bees on native biota is still the most comprehensive and relevant Australian study for the purpose of examining the potential impact of *Apis cerana* on Australian environments. He examines the distribution and abundance of honeybees in Australia, reviews the literature on the interactions between honeybees and Australian biota (in terms of competition, pollination effects and interactions with native fauna), reviews the management of honeybees in Australian environments and concludes with recommendations for future research. Some of these are reported below.

Butz-Huryn (1997) writes about the ecological impact of honeybees across the globe. She reports that there is a spectrum of honeybee impact on plant reproduction which is dependent on the level of pollination. Honeybee visits on flowers will result in different levels of pollination (major, secondary, incidental) depending on flowers and multiple other conditions. She notes that although there is a high potential for disturbance of native plant/pollinator relationships the evidence does not support this hypothesis. She summarises her argument thus:

- i) Few plant species are used intensively by honeybees, thus decreasing the opportunity for disturbance. Pollination studies show that honeybees are effective pollinators of some native plants and less effective pollinators of others; data are insufficient to show whether honeybee foraging on native plants significantly alters pollen and gene flow; honeybees do not physically damage plants; they are also unlikely to increase hybridization of native flora.
- ii) Experiments have not shown competition for nesting sites between honeybees and native fauna. The presence of honeybees, however, alters the foraging behaviour and abundance of some native fauna on flowers, but no studies have shown detrimental impacts of honeybees on population abundances of any native animals or plants. Anecdotal and quantitative reports of increased honeybee abundances on flowers compared with native fauna are often confounded with habitat changes induced by man.

Paini (2004b) reviewed the literature on the impact of *Apis mellifera* on a native bee species in the context of interspecific competition for limited floral resources to establish if there was any reduction of survival, growth and/or reproduction of the native bee species. He found that previously published research into honeybee / native bee competition had focused on floral resource overlap, visitation rates or resource harvesting, and any negative interaction had been interpreted as negative. However, he found that many of these studies had problems with sample size, confounding factors or data interpretation and suggested that further experimental work be conducted on fecundity, survival or population density to determine if the long-term survival of native bees is threatened (Paini 2004b).

Likely impacts – asserted and observed

Possible impacts have been variously expounded depending on the level and nature of private-public interest of the proponent. Social, economic and public health impacts have recently been investigated (Goswami and Antony 2010; Ryan 2010; Goswami and Antony 2011), however there is a scarcity of research on the environmental impact of the introduction of *Apis cerana* in Australia. In this context, it is critical to engage a wide range of possible stakeholders from the outset to ensure that their views are taken into consideration and to improve environmental outcomes. Environmental and conservation groups are key stakeholders whose attitudes to the introduction of *Apis cerana* are important to obtain. However, there was no widely published material available on

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this topic at the time of writing and therefore their views are unrepresented here. Industry, science and economic stakeholders' views are represented below albeit briefly.

The bee keeping industry state that “the Asian bee will take over the nesting hollows of native fauna. It can occupy small spaces. The Asian bee will compete with native fauna for nectar and pollen... The Asian bee has already been found in a nesting box in an aviary where it took over and killed the young ” (Australian Honey Bee Industry Council 2011). The honeybee industry have also published a web-based factsheet on the *Apis cerana* in which they claim that “ Spread of AB [Asian bee] will be like cane toads and rabbits – both deliberate introductions” (Secure foods save bees 2011). Further assessment of predicted environmental impacts noted by professionals and practitioners associated with the honeybee industry would prove useful and informative but are beyond the scope of this review.

From an applied science perspective, authors of a CSIRO submission on the future of the honeybee industry claim that “while the Asian bee (*Apis cerana*) poses a threat to pollination services overall, its impact is more likely to be environmental” (CSIRO 2007). In an RIRDC publication on the estimation of public costs arising from an incursion of *A. cerana*, economist Terry Ryan has argued that “*Apis cerana javana* are expected to replace *Apis mellifera* on a one for one basis. *Apis cerana javana* swarm 2 to 6 times more frequently, and have smaller colony sizes, than *Apis mellifera*. It is therefore assumed there would be greater environmental impacts if *Apis cerana javana* became endemic, even if they replaced the same number of *Apis mellifera*” (Ryan 2010). Ryan bases his assumptions on evidence provided by eminent CSIRO bee scientist Denis Anderson in personal communication. With reference to the Solomon Islands, Anderson writes that “the spread of the Asian honeybee through the Solomon Islands will have a severe impact on the environment and the extent of this impact warrants further investigation” (Anderson, Annand et al. 2010).

Given the invasion is relatively recent and there are no published studies of its environmental impact to date, actual impact of *A. cerana* on the Australian environment can therefore only be assessed given the (limited) data and careful observations of the Biosecurity Queensland Surveillance Manager and other experienced field officers. Findings to date include:

- *Apis cerana* nesting inside tree snake nest site
- *Apis cerana* nesting inside bird nest
- *Apis cerana* nesting inside compost bins, letter-boxes, car tyre rims, yacht mast, building sites and industrial areas
- Green ant, Rainbow bee eater and cane toad predation upon *Apis cerana* (de Jong, pers. comm. May 24th 2011).

On the basis of this data, it is unwise to make widespread generalisations about predicted environmental impacts of *Apis cerana*. However it is useful to draw out some possible implications and explore possible hypotheses in relation to the impact of *Apis cerana* on the Australian environment on the basis of evidence presented to date.

Hypotheses and questions

There are more questions raised by such a review than are answered in the published literature. Critical questions may include, but are not limited to the following:

- Are the differences between *Apis cerana* and *Apis mellifera* likely to generate different environmental impacts than those existing impacts of feral populations of *Apis mellifera*?

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- Is the java strain of *Apis cerana* more or less exotic to Australian biota and ecosystems in comparison with *Apis mellifera*? What impact will an incursion of *Apis cerana* have on a) plants b) native bees, c) vertebrates d) *Apis mellifera*? What kind and nature of competition/ co-existence will transpire between *Apis cerana* and these species?
- How far / how quickly will the current incursion of *Apis cerana* spread? What effect will climate change have on the distribution and abundance of *Apis cerana*? Would the Java genotype of *Apis cerana* adapt to cooler climates?
- Are there sufficient floral and nesting resources in Australian environments to support additional bee populations? Will this lead to increased or decreased survival of native and introduced species? Would it increase or decrease pollination effectiveness of native plant species? How will *Apis cerana* contribute (if at all) to the negative impact of invasive agricultural and environmental weeds?
- To what extent is it possible to manage feral populations of *Apis cerana*? What effect will current *Apis cerana* baiting and trapping efforts have on native species, managed hives and feral colonies of *Apis mellifera*?
- Against what benchmark do governments and regulators set investment prioritization budgets in relation to the proposed management of *Apis cerana*?

There are three possible scenarios examined here. In the light of each, further questions are raised and following this suggestions for management and recommendations are made.

- 1) *Apis cerana* will have a severe impact on Australian biota
- 2) *Apis cerana* will have a moderate impact on Australian biota
- 3) *Apis cerana* will have a minor impact on Australian biota

It is likely that both the severity and nature of the impacts will vary depending on habitat and geography, climate, management actions among other variables...However, there are no certainties about the future and it is clear that most of these predicted impacts are based on conjecture and assumptions about future behaviour based on past studies and models. For example, Brous and Keogh have determined that a change in climatic conditions might change the distribution of pollination agents and in particular the areas and times of the year where and when they can operate effectively. For invertebrates, it is foreseeable that warming across Australia would see their range shift south, but perhaps northern Australia conditions would become unsuited to *Apis mellifera* and favour Asian bee species currently confined to Asia (Brous and Keogh 2008).

Although this review does not conclusively establish evidence of harmful impacts from *Apis cerana* on Australian environments, it is clear that there are many reasons to be concerned about the potential impact of this invasive species and to question what more can be done. Management actions will depend upon a mix of pragmatic, scientific, socio-cultural and economic evidence and influence - however recommendations on these are far from certain or fixed.

Management recommendations

As a first principle, precaution is necessary. Both Oldroyd (Oldroyd 1998) and Paton (pers. Comm May 17 2011) recommend adherence to the precautionary principle around management of non-native bees. The former advocates caution specifically in areas of high conservation value. While neither author has directly commented on *Apis cerana*, there are sufficient similarities between *Apis cerana* and *Apis mellifera* to warrant a cautious approach to the management of invading *Apis cerana* and/or the ecosystems they threaten.

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Having said that, it is entirely possible that given the time elapsed since *Apis mellifera* was first introduced, any disruption to native plant/vector relationships from that incursion is likely to have already occurred. There may be both short term and longer term management measures that could be put into place quickly to prevent potentially disruptive interactions between *Apis cerana* and native Australian biota. Based on Anderson's (Anderson 1989) suggestions, these include:

- establishing and maintaining *Apis cerana*-free areas
- classifying natural habitat into *A. cerana* -free, *A. cerana* control or *A. cerana* affected areas for differential management of key native species;
- creating buffer zones around *A. cerana* -free and *A. cerana* -control areas
- controlling *A. cerana* populations via baiting (Austvet Plan, Version 3.1, 2009).
- recording key observations of all *A. cerana* colonies/swarms in a centralised database.

Research recommendations

Sufficient is known about Australian plant and animal communities to safely state that it is false to suggest honeybees will never have negative effects on nature conservation, just as it is false to suggest that they will have serious negative impacts in all circumstances (CSIRO 2007). One key area for future research is to determine where and when the risk of negative environmental impact from *Apis cerana* is highest such that limited resources are directed to areas of maximum return. So which research should be prioritised?

Research priorities

Stout and Morales (2007) provide an excellent starting point in establishing a list of research priorities around the impact of exotic bees. While these suggested priorities were initially proposed in the context of the impact of exotics on native bees, it is clear that their utility extends more broadly.

- 1) Firstly, studies on impacts of invasive pollinators should be extended to the landscape scale, along a longer temporal scale and should be carried out at the species and community level (Walther-Hellwig et al., 2006 cited in Stout and Morales (2007: 400-401).
- 2) Secondly, these studies need to be properly replicated in time and/or space (see for example Thomson 2004). Systems are naturally variable and in order to generate useful conclusions, rigorous experimental design is required.
- 3) Thirdly, given the rapid rate of new introductions, and the impracticality of conducting detailed experimental studies of the impact of exotic species on all native species in every region, it is critical to determine a set of decision criteria to improve decision making, monitoring and rapid response.
- 4) Fourthly, it is important to understand the pathology, virulence and cross infectivity of disease organisms carried by exotic bees and to increase detection mechanisms of these in live bees in order to improve quarantine measures.
- 5) Finally, there is an urgent need to consider the impacts of climate change on spatial and temporal shifts in invasive exotic pollinators and their interactions with native species.

References

Anderson, D., N. Annand, et al. (2010). Control of Asian honeybees in the Solomon Islands, Australian Government, Australian Centre for International Agricultural Research.

The sustainability of beekeeping with the European honeybee (*Apis mellifera*) in the Solomon Islands became threatened in 2003 when the exotic Asian honeybee (*Apis cerana*) was discovered on Guadalcanal and Savo Islands. These discoveries coincided with the demise on both islands of almost all managed European honeybees (*Apis mellifera*) and total cessation of honey production. An assessment of the incursions in 2004 concluded that the newly arrived bees had become well established on both islands, could not be eradicated, and would eventually spread to other islands. The losses of managed honeybees that coincided with the incursion were attributed to robbing by and increased competition for floral resources from the Asian honeybees. Soon after this assessment local stakeholders decided that efforts should be made to save the local beekeeping industry from the threat of the Asian honeybee.

This project was implemented in 2007 following a request to ACIAR for assistance from the Solomon Islands Government. The over-arching aims of the project were to (a) obtain more information on the Asian honeybee in the Solomon Islands and (b) develop methods that would assist Solomon Islands beekeepers reduce the negative impacts of the Asian honeybee on managed European honeybees. Extension and training activities were conducted during the project to address knowledge gaps, identify industry deficiencies and assist beekeepers in the uptake of new or improved beekeeping methods. Other project activities involved implementing surveillance for the Asian honeybee and determining the pest and disease status of the managed European and wild Asian honeybee populations.

The strain of Asian honeybee that arrived in the Solomon Islands is prone to swarming and produces very little honey. No attempts were made to domesticate it during this project, as ongoing efforts to do so in other regions have failed. Instead, research focussed on developing ways to reduce the negative impacts of the bee on managed European honeybees. The simplest way to achieve this was to improve the foraging competitiveness of the managed honeybees. Two options were available - permanent eradication or temporary suppression of the Asian honeybees. Permanent eradication was not viable as Asian honeybees were well established on both Guadalcanal and Savo Islands and possibly on other islands, leaving temporary suppression as the only viable option.

The method developed here for the temporary suppression of Asian honeybee populations relied on the use of the broad-spectrum insecticide fipronil to destroy feral Asian honeybee colonies within a designated area. This insecticide has been used as a slow acting poison for feral European honeybees and, when mixed with bait such as sugar-syrup and offered to foraging bees at 'bait-stations, allows the lured bees enough time to return to their colonies before poisoning them. Once inside European honeybee colonies, fipronil becomes dispersed and rapidly destroys the colonies. Before using the method on Asian honeybees in the Solomon Islands, all managed European honeybee colonies within and surrounding a designated area must be relocated to a distance of at least 5.5 km away from the nearest bait-station to prevent them being poisoned. Then, for 4-7 days between 10.00am and mid-day, foraging Asian honeybees within the designated area are lured to bait-stations (each erected 500 metres apart) that house feeders offering sugar-syrup rewards (60% sucrose diluted in water). The lured bees feed on the sugar-syrup and transport it to their respective colonies. When large numbers of bees have been regularly lured to the bait-stations (>500 arriving simultaneously, which is usually achieved after 4-7 days of luring), the sugar-syrup rewards are replaced at each station for a 1-hour period between 11.00am and mid-day with fresh sugar-syrup containing 0.05% fipronil (TERMIDOR® - residual termicide, active constituent 100g/l fipronil). The bait-stations are then removed and any remaining fipronil-laced sugar-syrup buried. After a withholding period of 4-6 weeks to allow the toxicity of the insecticide to break down in the destroyed Asian honeybee colonies, managed European honeybee colonies may be reintroduced into the designated area. This single application of fipronil destroys most of the feral Asian honeybee population within a

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designated area, thus improving the foraging competitiveness of managed European honeybees in that area. The method is cheap, effective and had no observable negative impacts on humans, domestic animals or wildlife. If beekeepers adopt this method in conjunction with the use a modified hive box that restricts entry to robbing Asian honeybees, further development of beekeeping in the Solomon Islands will be possible. However, beekeepers will need ongoing assistance in adopting these methods, and this should be a component of beekeeper training in future development programs.

Extension and training activities carried out during the project confirmed that beekeeping is a highly regarded activity in the Solomon Islands and there is much potential for expansion. Locally produced honey attracts a premium price and demand for it far outstrips supply. However, most beekeepers currently experience difficulties in accessing extension services, hive and honey processing equipment and new genetic stock (queen bees), and this negatively impacts on hive management and honey yields. Under these conditions it is difficult to recruit new beekeepers into the industry. Improvements in these areas should also be targeted in future beekeeping development programs.

The Asian honeybee that arrived in the Solomon Islands was confirmed using DNA fingerprinting techniques as the Java 'haplotype' of *A. cerana*. This is the same bee that has become invasive in neighbouring Papua New Guinea and more recently in northern Australia, following its artificial introduction into the Indonesian province of Papua from Java during the 1970's. Over the course of this project the bee continued to spread through the Solomon Islands. It is now well established on the Islands of San Cristobal (Makira Province), Guadalcanal (Guadalcanal Province), Savo, Florida (Central Province), New Georgia and Kolombangara (Western Province). It may also have recently entered Gizo Island (Western Province). Surveillance for the bee was implemented on the Islands of Malaita (Malaita Province), Ranongga, Vella Lavella (Western Province) and Choiseul (Choiseul Province), all still free of the bee. Ongoing and improved surveillance will allow the spread of the bee to be monitored, which will allow beekeepers to respond quickly to the bee.

The health status of Asian and European honeybees in the Solomon Islands was determined. Asian honeybees were found to carry the microsporidian pathogen *Nosema ceranae*, Kashmir bee virus and a Java strain of the parasitic mite *Varroa jacobsoni*. They do not host any other species of parasitic mite, including *V. underwoodi*, *Acarapis woodi* (the tracheal mite) or *Tropilaelaps* spp. European honeybees were found to be relatively disease-free compared to honeybees in other regions. They carry *N. ceranae* and evidence suggests they acquired it from the Asian honeybee after its arrival. For this reason, trade in live European honeybees (e.g. queen bees) and used beekeeping equipment should not be permitted from islands with honeybees to islands without Asian honeybees. European honeybees in the Solomon Islands also carry sacbrood and chronic bee paralysis viruses, but are free of *Ascosphaera apis* (the cause of chalkbrood Page 6 disease), *Melissococcus plutonius* (the cause of European foulbrood disease), *Paenibacillus larvae* (the cause of American foulbrood disease) and the parasitic mites, *V. destructor*, *A. woodi* and *Tropilaelaps* spp. The cane toad (*Bufo marinus*) is also a serious pest of managed European honeybees throughout the Solomon Islands. On islands currently inhabited by both European and Asian honeybees, the European honeybee colonies are regularly invaded by low numbers of adult female *V. jacobsoni*, which spread from the Asian honeybee colonies. However, these mites do not cause serious harm to the colonies, as they lack the ability to reproduce on the European honeybee brood. This situation will need to be continually monitored in the future in case the mite suddenly develops an ability to reproduce on European honeybee brood, as the same mite recently did in Papua New Guinea.

Anderson, D. L. (1994). "Non-reproduction of *Varroa jacobsoni* in *Apis mellifera* colonies in Papua New Guinea and Indonesia." *Apidologie* 25: 412-421.

The incidences and reproduction of the ectoparasitic mite, *Varroa jacobsoni* Oud, in colonies of the Asian hive bee, *Apis cerana* F, and the European honey bee, *A. mellifera* L, in Papua New Guinea, Irian Jaya and Java are described. At each locality and in colonies of each bee species, adult female mites were present in capped brood cells, with proportionally more drone than worker brood cells infested. In the *A. cerana* colonies, female mites reproduced only in capped drone brood cells. In *A. mellifera* colonies, there was no evidence of successful mite reproduction on either worker or drone brood. Although not reproducing on *A. mellifera* worker and drone brood, or on *A. cerana* worker brood, adult female mites were nevertheless feeding and surviving. The inability of female mites to reproduce in *A. mellifera* colonies resulted in small,

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persistent mite infestations in individual colonies that were maintained solely by mites spreading from nearby *A. cerana* colonies. There was no evidence that the mites' inability to reproduce in *A. mellifera* colonies resulted from extremely slow reproduction, inter-specific competition between *V. jacobsoni* and *Tropilaelaps clareae* D & B, resistant bee populations, or climatic conditions. These results have implications for finding and developing novel means of controlling *V. jacobsoni* in localities where the mite has become a serious pest of *A. mellifera*.

Anderson, D. L. (2008). Surveillance of parasites and diseases of honeybees in Papua New Guinea and Indonesia. , CSIRO.

Anderson, D. L. and M. J. Morgan (2007). "Genetic and morphological variation of bee-parasitic *Tropilaelaps* mites (*Acari: Laelapidae*): new and re-defined species." *Experimental and Applied Acarology* **43**(1): 1-24.

Mites in the genus *Tropilaelaps* are parasites of social honeybees. Two species, *Tropilaelaps clareae* and *T. koenigerum*, have been recorded and their primary hosts are presumed to be the giant honeybees of Asia, *Apis dorsata* and *A. laboriosa*. The most common species, *T. clareae*, is also an economically important pest of the introduced Western honeybee (*A. mellifera*) throughout Asia and is considered an emerging threat to world apiculture. In the studies reported here, genetic (mtDNA CO-I and nuclear ITS1-5.8S-ITS2 gene sequence) and morphological variation and host associations were examined among *Tropilaelaps* isolates collected from *A. dorsata*, *A. laboriosa* and *A. mellifera* throughout Asia and neighbouring regions. The results clearly indicate that the genus contains at least four species. *Tropilaelaps clareae*, previously assumed to be ubiquitous in Asia, was found to be two species, and it is here redefined as encompassing haplotypes (mites with distinct mtDNA gene sequences) that parasitise native *A. dorsata breviligula* and introduced *A. mellifera* in the Philippines and also native *A. d. binghami* on Sulawesi Island in Indonesia. *Tropilaelaps mercedesae* n. sp., which until now has been mistaken for *T. clareae*, encompasses haplotypes that, together with haplotypes of *T. koenigerum*, parasitise native *A. d. dorsata* in mainland Asia and Indonesia (except Sulawesi Island). It also parasitises introduced *A. mellifera* in these and surrounding regions and, with another new species, *T. thaii* n. sp., also parasitises *A. laboriosa* in mountainous Himalayan regions. Methods are described for identifying each species. These studies help to clarify the emerging threat of *Tropilaelaps* to world apiculture and will necessitate a revision of quarantine protocols for countries that import and export honeybees.

Anderson, D. L. and J. W. H. Trueman (2000). "*Varroa jacobsoni* (*Acari: Varroidae*) is more than one species." *Experimental and Applied Acarology* **24**: 165-189.

Varroa jacobsoni was first described as a natural ectoparasitic mite of the Eastern honeybee (*Apis cerana*) throughout Asia. It later switched host to the Western honeybee (*A. mellifera*) and has now become a serious pest of that bee worldwide. The studies reported here on genotypic, phenotypic and reproductive variation among *V. jacobsoni* infesting *A. cerana* throughout Asia demonstrate that *V. jacobsoni* is a complex of at least two different species. In a new classification *V. jacobsoni* is here redefined as encompassing nine haplotypes (mites with distinct mtDNA CO-I gene sequences) that infest *A. cerana* in the Malaysia-Indonesia region. Included is a Java haplotype, specimens of which were used to first describe *V. jacobsoni* at the beginning of this century. A new name, *V. destructor* n. sp., is given to six haplotypes that infest *A. cerana* on mainland Asia. Adult females of *V. destructor* are significantly larger and less spherical in shape than females of *V. jacobsoni* and they are also reproductively isolated from females of *V. jacobsoni*. The taxonomic positions of a further three unique haplotypes that infest *A. cerana* in the Philippines is uncertain and requires further study. Other studies reported here also show that only two of the 18 different haplotypes concealed within the complex of mites infesting *A. cerana* have become pests of *A. mellifera* worldwide. Both belong to *V. destructor*, and they are not *V. jacobsoni*. The most common is a Korea haplotype, so-called because it was also found parasitizing *A. cerana* in South Korea. It was identified on *A. mellifera* in Europe, the Middle East, Africa, Asia, and the Americas. Less common is a Japan/Thailand haplotype, so-called because it was also found parasitizing *A. cerana* in Japan and Thailand. It was identified on *A. mellifera* in Japan, Thailand and the Americas. Our results imply that the findings of past research on *V. jacobsoni* are applicable mostly to *V. destructor*. Our results will also influence quarantine protocols for bee mites, and may present new strategies for mite control.

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Australian Government, D. o. A. F. a. F. (2011). "The Asian Honey Bee in Australia." Retrieved 11 May 2011, from <http://www.daff.gov.au/animal-plant-health/pests-diseases-weeds/the-asian-honey-bee-in-australia>.

Asian honey bees were detected in 2007 in Queensland. They have been found in Cairns, at Mareeba and Lake Eacham, and as far south as Innisfail. Most Asian honey bee detections have been in the city and port areas of Cairns, and immediately to the south of Cairns in the Gordonvale and Alooomba districts. Current Response The response to 31 March 2011 included an eradication program to detect and destroy any Asian honey bee swarms and nests, the introduction of movement restrictions controlling managed bees and beekeeping equipment and a notification system so all hives reported could be destroyed. Activities to eradicate Asian honey bees in the Cairns region were funded by the Australian Government, state and territory governments and the Australian Honey Bee Industry Council (AHBIC) on behalf of its members. Biosecurity Queensland has managed the response to the detection of the Asian honey bee in Cairns on behalf of the Asian Honeybee National Management Group (NMG). The NMG is comprised of the Secretary of the Department of Agriculture, Fisheries and Forestry; chief executive officers of the national and state/territory departments of agriculture and primary industries across Australia, a representative of AHBIC and Plant Health Australia. The Asian Honey Bee National Management Group formed the view in January 2011 that eradication of the Asian honey bee is no longer technically feasible. This decision was based on a number of factors including: the bee's high sensitivity to changes and their tendency to frequently relocate nests the bee breeds rapidly and can travel long distances, particularly with assisted movement on vehicles and trains limitations of current surveillance methods (including such factors as terrain) which makes it difficult to locate all nests and destroy them. This decision does not mean that activities against the bee will cease and border control measures remain in force. Biosecurity officials from state and federal governments met with honey bee industry representatives and representatives from some pollination-reliant industries on 15 March 2011 to start the process of developing a National Transitional Containment Program for Asian honey bees. On 31 March, the Senate requested that the Consultative Committee on Emergency Plant Pests (CCEPP) meet again to reconsider the feasibility of eradicating the Asian honey bee. At this meeting (held on 7 April 2011), the committee, again, did not reach consensus on whether the Asian honey bee could be eradicated from Queensland. The committee was also presented with two last minute papers, and as a result, the meeting be suspended for one week so CCEPP members could consider these papers. After reconvening on 15 April 2011, and having considered the two papers, the committee again could not reach consensus about whether the Asian honey bee could be eradicated. The 15 April meeting did record unanimous and very positive support, in the context of future containment and management efforts, for both papers, especially the industry proposal concerning Asian honey bees. There was also universal support for a remote baiting trial but that was qualified by a need for more clarification about how the trial would work and what, if any, potential impacts there could be for other insects. The two papers did not provide any new supporting scientific data but will be used to inform future activities of the Asian Honey Bee Coordination Group. This expert coordination group consists of affected industries, the Commonwealth and each of the states and territories has been working to identify the best way forward to control the Asian honey bee. The CCEPP is comprised of plant health managers from each of the states and territories and the Commonwealth, as well as industry representatives. This is the established process under the Emergency Plant Pest Response Deed for determining the best response to outbreaks of exotic plant pests and diseases, and ensures that decisions are rigorous and based on scientific evidence. About the Asian Honey Bee The type of Asian honey bee strain identified in Australia is *Apis cerana java* strain. This strain originates from Java, Indonesia, however, is now spread throughout Papua New Guinea and the Solomon Islands. Asian honey bees, *Apis cerana*, are honey bees from southern and south eastern Asia with a variety of strains and sub-species found in China, India, Indonesia, Japan, Malaysia, Nepal, Bangladesh, the Solomon Islands and Papua New Guinea. The Asian honey bee (*Apis cerana*) is not as easily managed as the European forms of *Apis mellifera* (the European honey bee) and its pollination activity cannot be as easily controlled for managed pollination services. The bee produces less honey than European honey bees and thrives in the tropics. Asian honey bees are the natural host for the Varroa destructor and *Varroa jacobsoni* – species of parasitic mites that feed on the immature and adult bees. *Varroa destructor* and one form of *Varroa jacobsoni* are non-natural parasites of European honey bees; as a result in the countries where they are established these mites will kill out European honey bee colonies. Fortunately these mites have not been found on bees in Australia. The Asian honeybee is approximately 13 mm long, has yellow and black stripes on the abdomen. It aggressively protects nesting sites and stings, has a tendency to abscond from nests sites. These absconding colonies are believed to be able to travel up to about 10km, however more normally less than this.

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Breed, M. D., X. Deng, et al. (2007). "Comparative nestmate recognition in Asian honey bees, *Apis florea*, *Apis andreniformis*, *Apis dorsata*, and *Apis cerana*." Apidologie **38**(5): 411-418.

In nestmate recognition bioassays, *Apis florea*, *A. andreniformis*, *A. dorsata* and *A. cerana* do not exhibit aggressive responses. These negative results were obtained using three distinct techniques: pairings of bees between colonies, switching nest box locations (*A. cerana* only), and treatment with compounds known to serve as nestmate recognition pheromones in *A. mellifera*. This is in sharp contrast to previously observed responses in *A. mellifera*, which displays strong aggressive responses to conspecific non-nestmates in the same types of bioassays. *A. cerana* expresses nestmate recognition, but only under limited circumstances - when robbing is precipitated by honey harvesting or the merger of colonies by a beekeeper. Our results suggest that robbing of stored food may be more characteristic of *A. mellifera* than other species in the genus *Apis*, and consequently *A. mellifera* displays a more strongly developed response to conspecific non-nestmates than other *Apis* species.

Brous, D. and R. Keogh (2008). Pollination Australia: Biosecurity risk management. Canberra, Rural Industries Research and Development Corporation.

This report informs the pollination industry on issues relevant to the identification and the quantification of the risk associated with the incursion of *Varroa* mite (and other exotic pests and diseases) and the risk associated with structural change to the honeybee industry and pollination dependent industries.

The report is concerned with highlighting the key issues that need to be considered in identifying, prioritising and actioning strategies to manage the risks for pollinators and growers dependent upon pollination for the production of crops. Investment in risk management strategies will assist in securing reliable, consistent quality and cost effective pollination services, without which many Australian rural industries would not be productive.

The project has its genesis in the Honeybee Industry Linkages workshop hosted by the Rural Industries Research and Development Corporation (RIRDC) in Canberra in April 2007.

Butz Huryn, V. M. (1997). "Ecological impacts of introduced honey bees." The Quarterly Review of Biology **72**(3): 275-297.

Honey bees (*Apis mellifera* L.), native to Eurasia and Africa, have been introduced to most of the rest of the world. Many plant species are used by introduced honey bees, which suggests a high potential for disturbance of native plant/pollinator relationships. Few species are used intensively, however, thus decreasing the opportunity for disturbance. Pollination studies show that honey bees are effective pollinators of some native plants and less effective pollinators of others; they also reduce floral resources in some species with little or no pollination. Data are insufficient to show whether honey bee foraging on native plants significantly alters pollen and gene flow, but unusual foraging behavior by honey bees is not evident compared to many other pollinators. Honey bees do not physically damage plants; they are also unlikely to increase hybridization of native flora. Pollination by honey bees probably contributes little to the success of most weeds. Experiments have not shown competition for nesting sites between honey bees and native fauna. The presence of honey bees, however, alters the foraging behavior and abundance of some native fauna on flowers, but no studies have shown detrimental impacts of honey bees on population abundances of any native animals or plants. Anecdotal and quantitative reports of increased honey bee abundances on flowers compared with native fauna are often confounded with habitat changes induced by man.

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CSIRO (2007). The Future of the Australian Honey Bee Industry, CSIRO.

de Jong, W. (2011). Personal communication.

Dollin, A. (2011). "Australian native bees." Retrieved 30-05-2011, from <http://www.wheenfoundation.org.au/australian-native-bees.html>.

Goswami, S. and G. Antony (2010). Expected socio-economic impacts of the establishment of Asian Honeybees in Australia. Brisbane, Biosecurity Queensland.

Goswami, S. and G. Antony (2011). Expected socio-economic impacts of the establishment of Asian Honeybees in Australia. 9th Biennial Pacific Rim Conference of the Western Economic Association International. Brisbane.

This report assessed two aspects of the discovery of Asian honeybees (AHB) in Australia:

- The potential socio-economic impact on Australia of the unhindered spread of the AHB, using three scenarios of spread pattern; and
- The potential benefit of conducting an eradication program for the AHB.

The impact analysis indicated the potential for major socio-economic consequences from the unhindered spread of AHB over the 50 years of the analysis. Mean values of the discounted present values (PV) ranged from \$357 million (gradual spread) to \$5.53 billion (rapid spread through five nodes).

The majority of impact across all scenarios fell on the general public and government in the form of public health costs (56-74% of total) and public-nuisance costs (12-16% of total).

The potential benefit of conducting an eradication program (expected to cost a present value in 2008/09 of \$23 million) was assessed using cost-benefit analysis (CBA). The CBA indicated that conducting an eradication program for the AHB would be beneficial at all rates of spread analysed. The mean values of benefit cost ratios (BCR) estimated for the proposed eradication program versus the differing base cases ranged between 15:1 and 238:1.

Gross, C. (2001). "The effect of introduced honeybees on native bee visitation and fruit-set in *Dillwynia juniperina* (Fabaceae) in a fragmented ecosystem." Biological Conservation **102**: 89-95.

The endemic shrub *Dillwynia juniperina* is found in fragmented woodlands on the Northern Tablelands of New South Wales, Australia. The species obligatorily relies on pollinators to effect fruit-set and in this study the effect of fragmentation and the presence of the introduced honeybee on fruit-set was examined at two locations. Over two seasons *Dillwynia juniperina* was not pollenlimited indicating that flowers were saturated with pollen and that adequate bee servicing was occurring. Two native bee species (*Leioproctus* sp. 1 and *Lasioglossum* sp.) and the introduced honeybee, *Apis mellifera* L., were the most common visitors to flowers.

Bee abundance varied between sites with honeybees being more common than native bees at one site. Native bees were never the most dominant pollinator. Visitation data show that native bees spend more time at flowers than introduced bees, although on average honeybees visit slightly more flowers on a bush than do native bees. Visitation data also revealed that native bee presence at bushes is negatively correlated with the presence of honeybees at the same bushes. At one of the study sites, honeybees were very abundant, but very few native bees were ever recorded over the 3 years. Results show that flowers can be pollinated from a single visit by a honeybee or native bee. Extrapolation of visitation data showed that native bees could on their own adequately service flowers in some years at some sites while at other times introduced honeybees may be necessary to augment pollination services.

Gross, C. and D. Mackay (1998). "Honeybees reduce fitness in the pioneer shrub *Melastoma affine* (Melastomataceae)." Biological Conservation **86**: 169-178.

The agistment of managed hives of the introduced honeybee, *Apis mellifera*, in or adjacent to conservation areas in Australia is controversial. The effects, if any, of honeybee-foraging on native plants and their native-bee pollinators is poorly understood as most studies to date have concentrated on bird-pollinated systems. Furthermore, such studies have been undertaken in temperate Australia where feral and managed hives have been present for more than 150 years. In tropical Australia the impact of honeybees on the native biota is not known-yet the information is needed to assist with planning for the management of the large areas now under control of conservation authorities. We undertook a

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comparative study of honeybee and native bee pollination of the pioneer species *Melastoma affine* in tropical north Queensland, Australia, at a site where honeybees were recently introduced as managed hives. *Melastoma affine* is utilised by many animals in this ecosystem and its pollination mechanism is representative of several other pioneer species of the rainforest margin. *Melastoma affine* obligately relies on bee pollination to effect seed-set. Native bees were the most abundant floral visitors to *M. affine* although significantly more honeybees than native bees were sometimes present at flowers at the end of the morning. Honeybees were poor pollinators of *M. affine* compared with native bees. Honeybees deposited significantly less pollen on stigmas than native bees and honeybees actively removed pollen from stigmas. Consequently, fruit-set was less likely and seed-set was significantly lower in flowers to which honeybees were the last visitor, compared with cases where native bees were the last visitor and the last visitor to *M. affine* flowers was most often *A. mellifera*. In 91% of interactions between honeybees and native bees, native bees were disturbed from foraging at flowers by honeybees. Honeybees reduced fitness in *M. affine* in this study and we thus conclude that honeybees are an undesirable introduction in montane tropical-rainforest systems in Australia and based on our findings we strongly recommend that honeybees not be agisted in or adjacent to conservation areas in the wet tropics of Australia.

Gross, C. L., L. Gorrell, et al. (2010). "Honeybees facilitate the invasion of *Phyla canescens* (Verbenaceae) in Australia - no bees, no seed!" *Weed Research* **50**: 364-372.

Several environmental weeds rely on the pollination services of introduced bees. The transfer of this knowledge to weed control management has not been fully explored. In part, this may be because it is difficult to quantify the economic impact of environmental weeds. This diminishes the prospects for expensive research and development required for integrated weed management. In this study, we examine the reproductive ecology of *Phyla canescens*, a species native to South America that is an aggressive agricultural and environmental weed in many parts of the world. We found that *P. canescens* is self-compatible, but not capable of automatic self-pollination. A vector is required to effect seed set. Field studies showed that 45% of seeds produced through open pollination are viable. Using enclosure cages, we showed that non-native *Apis mellifera* L. (honeybee) was the primary floral visitor and pollinator. Honeybee abundance was positively correlated with *P. canescens* abundance. Within the study site of 0.51 ha, almost 500 000 seeds ha⁻¹ would be produced annually, as a result of honeybee pollination. This study shows that a shared evolutionary history is not required for honeybees to be successful pollinators. Facilitation is demonstrated through the obligate need for pollinators and the successful recruitment of the species through seed. Models for the control of feral honeybees in agricultural systems require development.

Hingston, A. B. (2006). "Is the exotic bumblebee *Bombus terrestris* really invading Tasmanian native vegetation?" *Journal of Insect Conservation* **10**(3): 289-293.

There has been a great deal of disagreement surrounding the capacity of *Bombus terrestris* to invade Tasmanian native vegetation. This paper reviews the conflicting findings of previous surveys of the invasion of Tasmania by *B. terrestris*, and presents new data from the 2004–2005 austral summer. From this, it is clear that *B. terrestris* has extensively invaded Tasmanian native vegetation. The new data provide strong evidence that *B. terrestris* is breeding in native vegetation in every region of Tasmania. More than 10 bumblebees were seen in one day at 153 locations in native vegetation, including 42 locations within 10 National Parks and 38 locations within the Tasmanian Wilderness World Heritage Area. Nests of *B. terrestris* were also found within two National Parks. These findings suggest that *B. terrestris* would also invade native vegetation in non-arid temperate regions of the Australian mainland, if it is introduced there.

Hingston, A. B., J. Marsden-Smedley, et al. (2002). "Extent of invasion of Tasmanian native vegetation by the exotic bumblebee *Bombus terrestris* (Apoidea: Apidae)." *Austral Ecology* **27**: 162-172.

Observations of the large earth bumblebee, *Bombus terrestris* (L.), in native vegetation were collated to determine the extent to which this exotic species has invaded Tasmanian native vegetation during the first 9 years after its introduction. The range of *B. terrestris* now encompasses all of Tasmania's major vegetation types, altitudes from sea level to 1260 m a.s.l., and the entire breadth of annual precipitation in the state from more than 3200 mm to less than 600 mm. Observations of workers carrying pollen, together with the presence of large numbers of bumblebees at many localities across this range indicate that colonies are frequently established in native vegetation. Evidence that colonies are often successful

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was obtained from repeated observations of the species during more than 1 year at particular sites. Unequivocal evidence of colonies was obtained from six National Parks, including four of the five in the Tasmanian Wilderness World Heritage Area (WHA). Indeed, the species has been present in the WHA for at least as long as it has in the city of Hobart, where it was first recorded. In southwestern Tasmania, evidence of colonies was obtained up to 40 km from gardens, 61 km from small towns and 93 km from large towns. Hence, contrary to previous suggestions, the species is established in the most remote parts of Tasmania and is not dependent on introduced garden plants. Given their strong record of invasion, it is likely that *B. terrestris* will form feral populations on the mainland of Australia and in many other parts of the world if introduced. Because of their likely negative impacts on native animals and plants, and potential to enhance seed production in weeds, the spread of bumblebees should be avoided.

Koeniger, N., G. Koeniger, et al. (2010). Honey bees of Borneo. Kota Kinabalu, Natural History Publications (Borneo).

Lee, B. (1995). Mites, bees, and plagues that are and might be. Partners in research and development. Canberra, ACT, ACIAR. **8**: 2-9.

Lo, N., R. S. Gloag, et al. (2010). "A molecular phylogeny of the genus *Apis* suggests that the Giant Honey Bee of the Philippines, *A. breviligula* Maa, and the Plains Honey Bee of southern India, *A. indica* Fabricius, are valid species." Systematic Entomology **35**(2): 226-233.

Two new taxa have been added to the existing molecular phylogenies of the genus *Apis*. The new phylogeny supports the accepted phylogenetic relationships of dwarf honey bees, giant honey bees and cavity-nesting honey bees. Based on Bayesian and maximum parsimony trees, our analysis supports recognition of *Apis indica*, the Plains Honey Bee of south India, as a separate species from *A. cerana*. Our analysis also supports recognition of the Giant Philippines Honey Bee, *A. breviligula*, as a separate species from *A. dorsata*.

Manila-Fajardo, A. C. and C. Cervancia (2003). "Performance of honey bees (*Apis mellifera* L.) in three ecosystems in Laguna, Philippines." Philippine Agricultural Scientist **86**(2): 146-157.

The population growth rates, pollen spectra and honey produced in managed and unmanaged, colonies of honeybees (*Apis mellifera*) were compared in three ecosystems in Laguna. Experiments were conducted at the Canlubang Industrial Estate, in the town of Bay and in the Makiling Forest Reserve representing the industrial, agricultural and forest environments, respectively, from August 30, 2000 to May 2002.

The population growth of *A. mellifera* in an agroecosystem was significantly higher than in the industrial and forest environments. The abundance of melliferous plants in the agroecosystem enhanced the population build-up of *A. mellifera*. The native species, *Apis cerana* and *Apis dorsata*, negatively affected the growth of *A. mellifera* colonies in the forest ecosystem by aggression and robbing of stores. Mites, *Varroa destructor*, chalk brood disease and bird predators were observed in all sites.

Among the three environments studied, the bees performed best in the agroecosystem in terms of population growth and honey production. Trace amounts of cadmium, lead and chromium were detected in pollen samples from the industrial ecosystem. Deltamethrin and cypermethrin were absent in the honey and pollen samples from the agroecosystem.

Fifty-one pollen types were identified from the samples. There was no predominant pollen source. Seven secondary pollen sources were identified: *Hygrophila lancea*, Acanthaceae type, Convolvulaceae types, *Mimosa diplotricha* var. *diplotricha*, *Mimosa pudica*, Leguminosae types and Palmae types. Family Leguminosae represented most of the pollen types observed. There was an overlap in the pollen types identified from the industrial ecosystem and the agroecosystem.

In spite of diversity in a forest ecosystem, the exotic species *A. mellifera* failed to exploit the nectar and pollen sources of most plant species. This indicates that *A. mellifera* has not indeed adapted to natural forest conditions in the tropics.

Moller, H. (1996). "Lessons for invasion theory from social insects " Biological Conservation **78**: 125-142.

Reproductive and dispersal modes of social insects mean that fundamentally different models may be required for predicting determinants of their invasions from those for sexually reproducing non-social animals or non-insects. This suggests that it is unrealistic to expect the same predictors of invasiveness will apply to all biota. Many species of social wasps, bees and ants are extraordinarily invasive. The main general advantage promoting invasiveness of social insects may be the flexibilities arising from having both individual and colony responses that enable them to withstand biotic resistance and to better match conditions in the receiving community. Social insect invasion case studies have revealed strong evidence for biotic resistance to invasions in some instances. Intercorrelated species characters and ecological variations in different disturbance regimes, regions, habitats and community histories hamper further advances in the understanding of invasion biology from comparing invasive and non-invasive species. More incorporation of models of conservation biology, community ecology and genetics may assist invasion biology. Experimentally designed release programmes and detailed follow-up studies of biological control agents could greatly assist the quest for better invasion models. More prolonged invasion case studies, where the underlying mechanisms of invasion are researched, and experimental manipulations are the best way that a more robust and predictive theory of invasions can be generated. Social insects provide splendid opportunities for such research.

Moritz, R. F. A., F. B. Kraus, et al. (2007). The size of wild honeybee populations (*Apis mellifera*) and its implications for the conservation of honeybees. openUP. December 2007.

The density of wild honeybee colonies (*Apis mellifera*) in the African dry highland savannahs was estimated in three Nature Reserves in Gauteng, South Africa (Ezemvelo, Leeuwfontein, Suikerbosrand) based on the genotypes of drones which were caught at drone congregation areas. Densities were estimated to range between 12.4 and 17.6 colonies per square kilometer. In addition colony densities were estimated in two German National parks (Müritz and Hochharz) and a commercial mating apiary. The density of colonies was significantly lower at the German sampling sites with estimates of 2.4–3.2 colonies per square kilometer, which closely matches the nation-wide density of colonies kept by beekeepers. This shows that the densities of colonies observed in wild populations under the harsh conditions of the African dry savannahs exceeds that of Germany by far, in spite of intensive beekeeping. The intensity of apiculture in Europe is therefore unlikely to compensate for the loss of habitats suitable for wild honeybees due to agriculture, forestry and other cultivation of land.

Navajas, M., D. L. Anderson, et al. (2009). "New Asian types of *Varroa destructor*: a potential new threat for world apiculture." Apidologie **41**(2): 181-193.

The invasion of the Western honey bee, *Apis mellifera*, by *Varroa destructor* is attributed to two mitochondrial haplotypes (K and J) that shifted last century from their primary host the Eastern honey bee, *A. cerana*, in north-east Asia. Here, mitochondrial DNA sequences (cox1, cox3, atp6 and cytb: 2700 base pairs) were obtained from mites infesting both Eastern and Western honeybees (respectively 21 and 11 colonies) from Asia including regions where the shifts first occurred. A total of eighteen haplotypes were uncovered in Asia (11 on *A. cerana* and 7 on *A. mellifera*). Two new variants of the K haplotype and two of the J haplotype were found on Western honeybees in what appeared to be well-established infestations. New haplotypes may represent a potential threat to *A. mellifera* worldwide. The extreme lack of polymorphism in the K and J haplotypes outside of Asia, can now be plausibly explained as being due to genetic 'bottlenecks' that occurred in Asia before and after mites shifted from their original Eastern honeybee host.

Oldroyd, B. P. (1998). "Controlling feral honey bee, *Apis mellifera* L. (Hymenoptera: Apidae) populations in Australia: Methodologies and costs." Australian Journal of Entomology **37**: 97-100.

The level of impact of feral honey bees on the Australian ecosystems is controversial but may include competition with native fauna for floral resources or nesting sites, inadequate pollination of native flora or undesirable pollination of exotic flora. The precautionary principle suggests that control of feral bees in areas of high conservation value would be desirable. This raises the question of the feasibility and cost of controlling or eradicating feral bees in conserved areas. Possible methods for controlling feral bees in Australia are reviewed. It is concluded that eradication is not feasible on a broad scale, but would be in small areas that are heavily used by the public.

Oldroyd, B. P., S. H. Lawler, et al. (1994). "Do feral honey bees (*Apis mellifera*) and regent parrots (*Polytelis anthopeplus*) compete for nest sites?" Australian Journal of Ecology **19**: 444-450.

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Oldroyd, B. P., E. G. Thexton, et al. (1997). "Population demography of Australian feral bees (*Apis mellifera*)."
Oecologia **111**(3): 381-387.

Honey-bees are widespread as feral animals in Australia. Their impact on Australian ecosystems is difficult to assess, but may include competition with native fauna for floral resources or nesting sites, or inadequate or inappropriate pollination of native flora. In this 3-year study we examined the demography of the feral bee population in the riparian woodland of Wyperfeld National Park in north-west Victoria. The population is very large but varied considerably in size (50-150 colonies/ km²) during the study period (1992-1995). The expected colony lifespan for an established colony is 6.6 years, that for a founder colony (new swarm), 2.7 years. The population is expected to be stable if each colony produces 0.75 swarms per year, which is less than the number predicted on the basis of other studies (2-3 swarms/colony per year). Therefore, the population has considerable capacity for increase. Most colony deaths occurred in the summer, possibly due to high temperatures and lack of water. Colonies showed considerable spatial aggregation, agreeing with earlier findings. When all colonies were eradicated from two 5-ha sites, the average rate of re-occupation was 15 colonies/km² per year. Ten swarms of commercial origin were released and were found to have similar survival rates to founder colonies. However, the feral population is self-sustaining, and does not require immigration from the domestic population.

Oldroyd, B. P. and S. Wongsiri (2006). Asian honey bees: biology, conservation, and human interactions. Cambridge, Massachusetts, Harvard University Press.

Otis, G. W. and J. Kralj (2001). Parasitic brood mites not present in America. Mites of the honeybee. T. C. Webster and K. S. Delaplane, Dadant 251-272.

Paini, D. (2004a). The impact of the European Honey Bee (*Apis mellifera*) on Australian Native Bees. School of Animal Biology, Faculty of Natural and Agricultural Sciences. Perth, University of Western Australia. **Doctor of Philosophy**.

Paini, D. (2004b). "Impact of the introduced honey bee (*Apis mellifera*) (Hymenoptera: Apidae) on native bees: a review." Austral Ecology **29**: 399-407.

Interspecific competition for a limited resource can result in the reduction of survival, growth and/or reproduction in one of the species involved. The introduced honey bee (*Apis mellifera* Linnaeus) is an example of a species that can compete with native bees for floral resources. Often, research into honey bee/native bee competition has focused on floral resource overlap, visitation rates or resource harvesting, and any negative interaction has been interpreted as a negative impact. Although this research can be valuable in indicating the potential for competition between honey bees and native bees, to determine if the long-term survival of a native bee species is threatened, fecundity, survival or population density needs to be assessed. The present review evaluates research that has investigated all these measurements of honey bee/native bee competition and finds that many studies have problems with sample size, confounding factors or data interpretation. Guidelines for future research include increasing replication and using long-term studies to investigate the impact of both commercial and feral honey bees.

Paini, D. and J. Roberts (2005). "Commercial honey bees (*Apis mellifera*) reduce the fecundity of an Australian native bee (*Hylaeus alcyoneus*)."
Biological Conservation **123**(1): 103-112.

Paini, D. R., M. R. Williams, et al. (2005). "No short-term impact of honey bees on the reproductive success of an Australian native bee." Apidologie **36**: 613-621.

The European honey bee was introduced to Australia 180 years ago and feral populations now occupy most coastal environments. Although much debate has taken place regarding the possible impact of honey bees on Australian native bees, there has been little direct research. This study presents the results of a replicated Before-After Control-Impact (BACI) experiment simulating the putative impact of feral honey bees on an undescribed species of Australian solitary bee (*Megachile* sp. M323/F367). Although a large resource overlap occurred between the two species, there was no significant change in the reproductive success of the native bee. The realised precision of the experiment was assessed and showed appropriate sensitivity for three important reproductive variables. The native bee, being better

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adapted to the high summer temperatures experienced during the period of this experiment, may be able to withstand honey bee competition.

Paton, D. C. (1993). "Honeybees in the Australian Environment." *BioScience* **43**(2): 95-103.

Paton, D. C. (2008). Securing Long-Term Floral Resources for the Honeybee Industry. Canberra, Rural Industries Research and Development Corporation: 1-56.

Peng, Y.-S., Y. Fang, et al. (1987). "The resistance mechanism of the Asian Honey Bee, *Apis cerana* Fabr., to an ectoparasitic mite, *Varroa jacobsoni* Oudemans." *Journal of Invertebrate Pathology* **49**: 54-60.

A behavioral and physiological resistance mechanism of the Asian honey bee (*Apis cerana*) to an ectoparasitic mite, *Varroa jacobsoni*, which causes severe damage to the European honey bee (*Apis mellifera*) in the beekeeping industry worldwide, is reported here for the first time. Parasitism by the mite induced Asian worker bees to perform a series of cleaning behaviors that effectively removed the mites from the bodies of the adult host bees. The mites were subsequently killed and removed from the bee hives in a few seconds to a few minutes. The grooming behavior consists of self-cleaning, grooming dance, nestmate cleaning, and group cleaning. Worker bees can also rapidly and effectively remove the mites from the brood. The European bee showed cleaning behavior at low frequency and generally failed to remove the mites from both the adult bees and the brood.

Pimentel, D., S. McNair, et al. (2001). "Economic and environmental threats of alien plant, animal, and microbe invasions." *Agriculture Ecosystems and Environment* **84**: 1-20.

Over 120,000 non-native species of plants, animals and microbes have invaded the United States, United Kingdom, Australia, South Africa, India, and Brazil, and many have caused major economic losses in agriculture and forestry as well as negatively impacting ecological integrity. Some introduced species, like corn (*Zea mays* L.), wheat (*Triticum* spp.), rice (*Oryza sativa* L.), plantation forests, domestic chicken (*Gallus* spp.), cattle (*Bos taurus*), and others, are beneficial and provide more than 98% of the world's food supply. Precise economic costs associated with some of the most ecologically damaging alien species are not available. Cats (*Felis catus*) and pigs (*Sus scrofa*), for example, are responsible for the extinction of various animal species, however, it is impossible to assign monetary values to species forced to extinction. The estimate is that non-native species invasions in the six nations are causing more than US\$ 314 billion per year in damages.

Punchihewa, R. W. K. (1994). Beekeeping for honey production in Sri Lanka: management of asiatic hive honeybee *Apis cerana* in its natural tropical monsoonal environment, Sri Lanka Department of Agriculture Canadian International Development Agency.

Pyke, G. (1990). Apiarists versus scientists: a bittersweet case. *Australian Natural History*. **23**: 386-392.

Rural Industries Research and Development Corporation and Horticulture Australia Limited (2010). "Pollination Aware factsheet." Retrieved 12 May 2011, from [file:///localhost/%20http://www.honeybee.org.au/pdf/PollinationAwareFactSheet.pdf](http://localhost/%20http://www.honeybee.org.au/pdf/PollinationAwareFactSheet.pdf).

Ruttner, F. (1988). Biogeography and taxonomy of honeybees. Berlin, Springer-Verlag.

Ryan, T. (2010). Estimating the Potential Public Costs of the Asian Honey Bee Incursion. Canberra, ACT, Rural Industries Research and Development Corporation (RIRDC).

Sakagami, S. F. (1959). "Some interspecific relations between Japanese and European honeybees." *Journal of Animal Ecology* **28**(1): 51-68.

Saunders, D. A. (1979). "The Availability of Tree Hollows for Use as Nest Sites by White-tailed Black Cockatoos." *Wildlife Research* **6**(2): 205-216.

Data on nest hollows were collected from four study areas throughout the range of the short-billed form of the white-tailed black cockatoo, *Calyptorhynchus baudinii latirostris*, in south Western Australia. Hollows in trees are formed as a result of some destructive agent such as termites or fungi attacking the heartwood of the tree and breaking down the structure of the wood cells. The breaking off of part of the

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tree provides access to the hollow from the outside, and allows it to be used as a nest site. Throughout their breeding range, white-tailed black cockatoos will nest in any species of eucalypt which has a hollow of suitable size. The aspects of the entrances of hollows are not randomly distributed among compass groups, but the birds' selection of hollows was random. The aspect, depth to the floor and height of the entrance from the ground do not affect the success or failure of the nesting attempt. Female white-tailed black cockatoos searching for and preparing nest hollows chase female conspecifics from an area around their prospective nest tree. They continue this activity until they are incubating; this may result in suitable hollows not being accessible to other females. The rate of loss of hollows was 4.8 and 2.2% at two of the study areas. Hollows are being destroyed by all causes, particularly clearing for agriculture, faster than they are being created. Guidelines for the management of woodland must be drawn up so as to maintain a continuing supply of mature trees and protect hole-nesting species.

Secure foods save bees (2011). "Food security needs bee security: Fact Sheet – Asian Bee (*Apis cerana*) Java Strain (17/2/2011)." Retrieved 26-05-2011, from <http://www.securefoodssavebees.com/documents/Fact Sheet on Asian Bee-Feb2011.pdf>.

Semmens, T. D. (1996). "Flower visitation by the bumble bee *Bombus Terrestris* (L.) (Hymenoptera: Apidae) in Tasmania." *Australian Entomologist* **23**(2): 33-35.

To date the bumble bee *Bombus terrestris* (L.), first detected in Tasmania in February 1992, is known to have visited 156 introduced and 14 native species of plants there.

Senate Rural Affairs and Transport References Committee (2011). Science underpinning the inability to eradicate the Asian honey bee, Senate.

On 22 March 2011, the Senate referred the following matter to the Senate Rural Affairs and Transport References Committee for inquiry and report by 8 April 2011: (a) the science underpinning the technical assumption that *Apis cerana*, the Asian honey bee, cannot be eradicated in Australia; (b) the science underpinning the assumption that the Asian honey bee will not spread throughout Australia; (c) the science relating to the impacts of the spread of the Asian honey bee on biodiversity, pollination and the European honey bee; and (d) the cost benefit of eradication of the Asian honey bee.

Simpson, S. R., C. L. Gross, et al. (2005). "Broom and honeybees in Australia: an alien liaison." *Plant biology*(7): 541-548.

Stokes, K. E., Y. M. Buckley, et al. (2006). "A modelling approach to estimate the effect of exotic pollinators on exotic weed population dynamics: bumblebees and broom in Australia." *Diversity and Distributions* **12**(5): 593-600.

Stout, J. C., A. R. Kells, et al. (2002). "Pollination of the invasive exotic shrub *Lupinus arboreus* (Fabaceae) by introduced bees in Tasmania." *Biological Conservation* **106**: 425-434.

Exotic plant invasions threaten ecological communities world-wide. Some species are limited by a lack of suitable pollinators, but the introduction of exotic pollinators can facilitate rapid spread. In Tasmania, where many non-native plants are naturalised, exotic honeybees (*Apis mellifera*) and bumblebees (*Bombus terrestris*) have become established. We determined how these species affect the pollination of *Lupinus arboreus*, an invasive, nitrogen-fixing shrub, which is rarely visited by native pollinators. The proportion of flowers setting seed and the number of ovules fertilised per flower were positively related to the visitation rates of both exotic bee species. There was no effect of bee visitation rates on the proportion of seeds aborted prior to maturity, possibly due to postfertilisation environmental constraints. We conclude that the spread of *B. terrestris* may not alter the fecundity of *L. arboreus* because of the pollination service provided by *A. mellifera*, and discuss potential interactions between these two bee species.

Stout, J. C. and C. L. Morales (2009). "Ecological impacts of invasive alien species on bees." *Apidologie* **40**(3): 388-409.

We review direct and indirect impacts of invasive alien species (focussing on plants and insects) on native bees worldwide. Although there is a rapidly growing body of research into the effects of invasive alien

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plants on native plant pollination via disruption of native mutualisms, there has been little research on the impacts of invasive alien plants directly on bees. Such impacts are likely to vary according to the taxon of plant, the functional specificity of the native bees, and ecosystem context. Conversely, there have been more attempts to document impacts of invasive alien social bees on native bees. Most of these studies only indirectly evaluate competition for resources, have focused on a few native species and findings are sometimes contradictory. However, some studies showed strong negative impacts, suggesting that effects might be species-specific. Additionally, pathogen spillover and reproductive disruption due to interspecific mating has been demonstrated among some closely related taxa. Where we lack unequivocal evidence for impacts however, this should not be interpreted as lack of effect. We recommend that future studies are robustly designed and consider impacts on genetic, species (particularly solitary bees) and ecosystem biodiversity.

Thomson, D. (2004). "Competitive Interactions between the Invasive European Honey Bee and Native Bumble Bees." *Ecology* **85**(2): 458-470.

Biological invasions represent both an increasingly important applied problem and a tool for gaining insight into the structure of ecological communities. Although competitive interactions between invasive and native species are considered among the most important mechanisms driving invasion dynamics, such interactions are in general poorly understood. The European honey bee (*Apis mellifera*) is a widespread and economically important invader long suspected to competitively suppress many native bee species. Yet the extent to which this introduced species alters native communities remains controversial, reflecting ongoing debate over the importance of resource competition in regulating pollinator populations. I experimentally tested the effects of competition with *Apis* on colony foraging behavior and reproductive success of a native eusocial bee, *Bombus occidentalis* Greene, in coastal California. *B. occidentalis* colonies located near experimentally introduced *Apis* hives had lower mean rates of forager return and a lower ratio of foraging trips for pollen relative to nectar. Both male and female reproductive success of *B. occidentalis* were also reduced with greater proximity to introduced *Apis* hives. Reproductive success correlated significantly with measures of colony foraging behavior, most strongly with the relative allocation of foraging effort to pollen collection. This pattern suggests that *B. occidentalis* colonies exposed to competition with *Apis* experienced increased nectar scarcity and responded by reallocating foragers from pollen to nectar collection, resulting in lowered rates of larval production. These results provide evidence that *Apis* competitively suppresses a native social bee known to be an important pollinator, with the potential for cascading effects on native plant communities. This work also contributes to a greater understanding of the role competitive interactions play in pollinator communities, particularly for social bees.

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